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PHYSICAL TECHNICS;

OR,

TEACHER'S MANUAL OF PHYSICAL MANIPULATION,
ETC.

BY

ALFRED P. GAGE, A.M.,

AUTHOR OF "ELEMENTS OF PHYSICS."

BOSTON:
PUBLISHED BY THE AUTHOR.
1884.

Entered according to Act of Congress, in the year 1884, by
ALFRED P. GAGE,
in the Office of the Librarian of Congress, at Washington.

J. S. Cushing & Co., Printers, 115 High Street, Boston.

0237.15-9.5

PREFACE.

IT has been our aim to collate in this volume something of value to every teacher of Physical Science. For valuable suggestions and aid in our efforts, we are deeply indebted to Prof. W. LeConte Stevens of Packer Institute, Brooklyn, N.Y.; Prof. M. B. Crawford, Wesleyan University, Middletown, Conn., and Rev. J. G. Griffin of Ottawa College, Canada. Mr. Arthur W. Goodspeed of Harvard University prepared the key to the solution of problems. Messrs. J. S. Cushing & Co., Boston, are entitled to the credit for the excellence of the typography, and Messrs. Berwick & Smith, Boston, for the presswork.

AUTHOR.

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PART I.

LABORATORY EXERCISES.

PROPERTIES OF MATTER.—DYNAMICS.

GRAPHICAL METHOD OF REPRESENTING VARIABLE QUANTITIES.

SUPPOSE that we have two quantities, x and y, so related to each other that any change in one alters the other; for example, let x represent the interest, compound or simple, for a term of y years. Take a piece of engineer's paper, Fig. 1, divided into squares by equidistant vertical and horizontal lines. Select one of each of these lines to start from. The vertical line is called the *axis of Y*, and the horizontal line the *axis of X*, and their intersection the *origin*. Take point a as the origin, and let the horizontal spaces to the right represent the number of years, and the vertical spaces multiples of the first year's interest; then points a', a'', a''', etc., represent the interest at the end of the first, second, third, etc., years. Connect these points by a straight line aA. Now, if we take any point, as c, in this line, and connect it with the axis Y by a horizontal line nc, and with the axis X by vertical line mc, the former will represent the time and the latter the interest

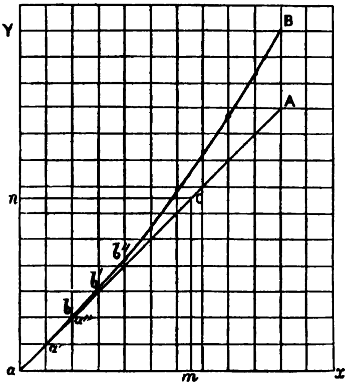

Fig. 1.

which has accrued at that time. The line *nc* is called the *abscissa*, and the line *mc* the *ordinate* of the point *c*. In a similar manner are found points *b*, *b'*, *b''*, etc., representing the *compound* interest at the end of the second, third, and fourth years. Having connected these points by the curved line *aB*, the ordinate of any point in this line will represent the compound interest which has accumulated at the time represented by its abscissa. What does the point *A* represent? the point *B*? the line *AB*?

EXPERIMENT 1. Construct a number of curves representing familiar phenomena, as the changes of temperature during the day or year, barometric changes, the velocity of a falling body, the declination of the magnetic needle at New York City (see p. 83) from 1680 to 1880, volumes of a given amount of air corresponding to different pressures, etc.

CRYSTALLOGRAPHY.

EXP. 2. Make saturated solutions of various substances, such as ammonium chloride, ammonium oxalate, potassium nitrate, cuprum nitrate, potassium bichromate, ferrum sulphate, barium chloride, urea dissolved in alcohol, etc., and flow slips of well-cleaned glass with each of these solutions. Allow them to drain for a few seconds, and then, with a microscope or common magnifying glass, watch the growth of the crystals as they form upon the glass.

EXP. 3. If the teacher possesses a porte-lumière, or a stereopticon, he should project the above on a screen by using the wet slips of glass as he would use the ordinary stereopticon slides. If the growth of crystals is slow, as is apt to be the case when the liquids are not fully saturated, it will be well to warm the slips of glass by waving them over a Bunsen or alcohol lamp flame, and then pour the solutions upon the warm glass.

It would be well to encourage pupils to collect cabinets of crystals. The crystals should be preserved in small, well-stoppered bottles or test-tubes. Single crystals may be mounted on heads of pins, the points of the pins being thrust into cork so as to hang from the same inside the bottles.

Exp. 4. Examine with a common magnifying glass a freshly broken surface of cast iron, and observe the crystalline appearance of the fracture.

Exp. 5. Make a cold saturated solution of table salt, and allow it to stand several days. As the water evaporates, small crystals of salt will be formed. *Make drawings of crystals of all the substances used.*

VISCOSITY.

Exp. 6. (By Sir Wm. Thomson.) Take a cake of shoemaker's wax, 18 inches in diameter and 3 inches thick, and place it in a shallow cylindrical glass vessel. Below the cake place a number of corks, and on top of the cake some lead bullets. Fill the glass vessel with water to prevent great variations in temperature. In about a year's time the corks will float up through the wax to the top, while the bullets sink to the bottom, showing the *viscous* nature of the wax.

Exp. 7. Take a strip of sheet lead about 40^{cm} long and 2^{cm} wide, and attach to one end by means of a clamp of some kind a weight of about 300^{g}. Support the whole in a vertical position by means of another clamp applied to the upper extremity, and note at regular intervals of time, by means of a fixed scale placed beside it, the elongation which has taken place. Draw curves of viscosity, the ordinates marking the elongation and the abscissas the units of time.

Exp. 8. Determine the viscosity of glass. Get a glassblower to make a coil about 6^{cm} in diameter and 20^{cm} long from a piece of glass tubing about 1.5^{m} long and 6^{mm} in diameter. Suspend the coil in a vertical position, and attach to the lower extremity a weight of about 20^{g}.

Exp. 9. Determine the viscosity of wires of different metals wound into coils, and draw curves of viscosity for each.

SOLUBILITY.

Exp. 10. Compare the solubility in cold and in hot water of alum, saltpeter, common table salt, white vitriol (zinc sulphate), etc. In each case take 10^{cc} of cold water in a test-tube; pulverize the solid to be tested, weigh out 50^{g} of it, place a small quantity in the test-tube, cover the mouth with a finger, shake well, and observe the rapidity with which it is dissolved. Continue to add small quantities at a time (smaller as it approaches the saturated point), as long as it is dissolved; and, when saturated, weigh the remaining solid. Its weight $= a$ grams. Then $\frac{50 - a}{10} = x$, the solubility of the given substance in cold water.

Exp. 11. Next suspend the test-tube in boiling water, and continue adding small quantities of the substance till saturated. Weigh the remaining solid; its weight $= b$. Then $\frac{50 - b}{10} = y$, the solubility of the given substance in water almost boiling. Prepare blanks, and record your results as follows: —

Name of Substance.	Solubility in Water.	
	Cold.	Almost Boiling.
Alum	0.15	3.6

The *solubility* of a substance is the weight in grams of the solid which 1 gram (1^{cc} when water is used) of the solvent requires to form a saturated solution. In stating the solubility of a substance, ought the temperature of the solvent to be given? What weight of alum will 40^{cc} of cold water dissolve?

What weight will the same quantity of hot water dissolve? How does the solubility of alum in hot and cold water compare?

Exp. 12. Ascertain approximately the solubility of the substances used in the last experiment in cold alcohol.

Exp. 13. Put a granule of gum mastic in a test-tube containing water, and shake. Do the same with granules of iodine and analine.

Exp. 14. Repeat the last experiment, using alcohol as a solvent.

Exp. 15. Pour the solution of mastic obtained in the last experiment into a tumbler of water.

Exp. 16. To 4^{cc} of a concentrated solution of sodium sulphate add 2^{cc} of alcohol.

In which are organic substances—*i.e.*, substances of animal or vegetable origin — more commonly soluble, in water or in organic solvents such as alcohol? Can one liquid diminish the solvent power of another?

ABSORPTION AND DIFFUSION.

Exp. 17. Take about 1^{cc} of ammonia water in a test-tube, and immerse the lower end of the tube in hot water; in about a minute close the mouth of the tube with the thumb, invert it in a vessel of cold water, and remove the thumb.

Exp. 18. Make a paste of plaster of Paris about 1^{cm} in depth. Take a glass tube 20^{cm} long and 2^{cm} in diameter, and thrust one end vertically into the paste, and hold it there until the paste hardens. Allow the tube to stand for a day or more to allow the excess of water in the plaster plug to evaporate. Hold the tube vertically, with the plugged end upward, and introduce a rubber tube connected with a gas jet, and fill with illuminating gas. Thrust the open end just beneath the surface of water, and hold it there for a few minutes. The water will gradually rise in the tube in consequence of the osmose of the gases.

Exp. 19. Pour into a saucer about 5^{cc} of ether or bisulphide of carbon, and notice the rapidity with which its vapor diffuses through the air in a room, its presence being recognized by the sense of smell. The molecules issue from the bottle with great velocity; and, if their progress were not interrupted by striking against the air particles, the room would be instantaneously permeated by the odor.

DENSITY, ETC.

Exp. 20. Prepare a concentrated solution of common salt, sulphate of soda, or sulphate of zinc. Introduce first into pure water, then into the solution a wooden demonstration hydrometer like that described in § 64, Physics, and, noting the depths to which it sinks in each liquid, calculate from the data obtained the density of the solution. In doing this, the pupil will intuitively grasp the philosophy of the hydrometer.

Exp. 21. Place an ordinary heavy-liquid hydrometer in water; then add gradually (as fast as it will dissolve) powdered sulphate of soda, stirring with a glass rod, and note from time to time the density of the liquid. Draw a curve of density representing the density by abscissas, and the number of grams of solid dissolved by ordinates.

Exp. 22. Place a light-liquid hydrometer in cold water, then in water at a temperature of about 80° C., and note the density of the two waters. Why must the standard of specific gravity be given at a definite temperature?

Exp. 23. Measure the capacity of some small cavity. First weigh the article containing the cavity, then weigh the same with the cavity filled with mercury, divide the difference between the two weights by the specific gravity of mercury, and the quotient will be the capacity in cubic centimeters.

Exp. 24. According to the principle of parallel forces, the two arms of a balance beam ought to be precisely equal; otherwise, unequal weights will be required to produce equilibrium. Test your laboratory balances by placing weights in the two pans until the beam becomes horizontal. Then interchange the contents of the pans; if the beam remains horizontal, the arms are equal, otherwise it will descend on the side of the longer arm.

Exp. 25. *Paradox.* Take a strip of tin 50^{cm} in length and 6^{cm} in width, and bend it into the form of a circular hoop; solder the two ends together. At some point in the interior of the hoop solder a lump of lead weighing about half a pound. This hoop may now be placed upon an inclined plane in such a position that it will *apparently* roll up hill.

Exp. 26. Bore holes about 2^{mm} in diameter with the point of a pen-knife blade in the opposite ends of a hen's egg; blow the contents out. Drop pulverized rosin through the hole in the large end so as to cover the interior surface of the small end; then pour melted lead through the same hole, so as to "load" the small end. In whatever way you place the shell, it will stand on the small end.

Exp. 27. Take a long glass tube (the longer the better), closed at one end with a tight-fitting cork, fill it with water, and suspend it in a vertical position by a light spiral spring from the ceiling. Suspend at the top of the water column a number of bullets attached to the tube by a thread. With a flame, burn the thread; during the descent of the bullets through the water, the spring contracts and the tube rises. Account for this phenomenon, and make a practical application of the principle involved. When any portion of our atmosphere ascends, in consequence of a denser portion descending, how will the pressure of the lower strata be affected?

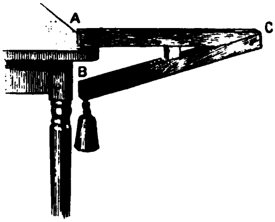

Fig. 2.

Exp. 28. Prepare a V-shaped bar like that shown in Fig. 2, the bar *AC* being about 3 feet long; place it so that the end will overlap the table two or three inches, and hang a heavy weight or a pail of water on the hook *B*, and the whole will be supported. Rock the weight back and forth by raising the end *C* and allowing it to fall. What kind of equilibrium is this? Remove the weight, and the bar falls to the floor. Why?

Exp. 29. In the small end of an egg make a hole about 2^{mm} in diameter, and place it, the small end downward, in a wine-glass, so that the end of the egg will be within 1^{mm} of the bottom of the glass. Place the whole under the receiver of an air-pump, and exhaust the air. The air which is contained in a small sack at the large end of the egg will expand and expel some of the contents of the egg. But, on re-admission of air to the receiver, the pressure of the air will drive the fluid back into the shell.

EXPERIMENTS WITH EIGHT-IN-ONE APPARATUS.

Exp. 30. Insert the stopper *a* (Fig. 3) in the base, and remove the caps *b*, *c*, *d*, and *e*, and fill the cup *f* with water so that the liquid surface will be above the bend *g*, and *the lateral pressure of liquids* will be shown by the issue of liquids from the side orifices. (It may be necessary to remove temporarily the cap from *h* to allow the air in the tube to escape.)

Exp. 31. That *pressure increases with the depth* is shown by the increase of velocity of the streams as the depth increases.

Exp. 32. Remove the stopper *a*, and the liquid ceases to flow from the side orifices, showing that *during the free fall of liquids there is no lateral pressure.*

Exp. 33. Replace the stopper *a*, and the caps on *b*, *c*, *d*, and *e*, and remove the cap from *h*, and connect with this tube, by means of a rubber connector, a glass tube *i*; and, elevating the latter at various angles, *the exact paths of projectiles* at these angles are shown.

Exp. 34. Remove the stopper *a* and the cap from *j*, and close all the other orifices; connect with the tube *j* a glass tube *k*, the lower end of which dips into a vessel of liquid *m*, and this liquid will be drawn up the tube, illustrating the action of the *Sprengel pump.*

Exp. 35. It will be seen that the receiver *f* is a *Tantalus cup*, and that here it is turned to a practical use, inasmuch as it will not suffer the liquid to flow until the vessel is full, and all is ready for the experiment.

Exp. 36. It is evident that, when the cap is removed from *h*, and the tube *i* is suitably elevated, the instrument becomes a *siphon-fountain*.

Exp. 37. The fountain may easily be made to represent an *intermittent spring or fountain* by placing above the receiver a large vessel of water *n*, from which liquid is siphoned into the receiver *f*. The siphon delivery being smaller than that of the Tantalus tube, it is evident that the fountain will operate intermittently and at regular periods, inasmuch as the liquid will not flow from the Tantalus cup until it is filled to the level of the bend, and will then flow until the cup is empty.

Exp. 38. Place the apparatus from 8 to 12 ft. above the ground, remove the caps *b*, *c*, *d*, and *e*, fill the cup *f* with water, and note the maximum horizontal distance, measured on the ground, which each stream attains. Draw a curve of pressure, the ordinates representing the distance of each orifice below the bend *g*, and the abscissas the horizontal distances attained respectively by the streams. Draw a curve of velocity on the principle that the velocity varies as the square root of the pressure or *head* of water, the ordinates representing the velocity and the abscissas the pressure at the several orifices.

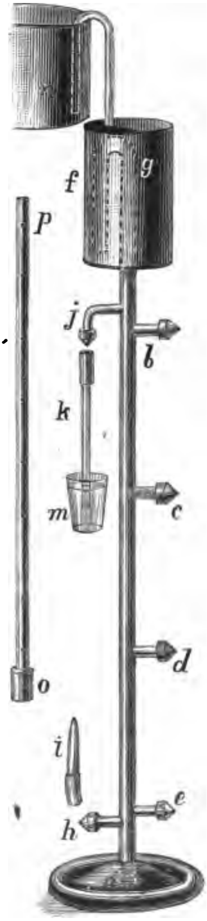

Fig. 3.

Exp. 39. Stop up all the orifices but one, and note the number of seconds it takes to empty the cup through that orifice; do the same with each orifice, and draw a *time curve* representing the time by ordinates and the distance below the bend *g* by abscissas.

Exp. 40. Provide glass tubes 20^{cm}, 40^{cm}, 60^{cm}, and 80^{cm} long, and of uniform bore; connect them successively with the tube *h*, and note the time consumed in emptying the cup through each. Draw a curve of *hydraulic friction*, the abscissas representing the increment in length of tube, and the ordinates the increment in time consumed, or friction.

Exp. 41. Keep the cup constantly full by pouring or siphoning water into it. Close all the orifices save one, the stream from which you wish to represent graphically. Determine the horizontal projection or *random* of suitable points of the stream by measuring perpendicularly from a line let fall from the orifice; also determine the vertical distance of each point below the orifice; then, by means of corresponding ordinates and abscissas, and on a scale of equal parts, construct a graphical representation of the stream. In similar method represent the paths of the streams from the several orifices.

Exp. 42. Connect the glass tube *i* with *h*, elevate it to any desired angle, fix it firmly in this position, and make measurements similar to those in the last experiment, except that the vertical distances are to be measured *upward* from the orifice *h*; construct from the data obtained a graphical representation of the path of a projectile directed at this angle. It will be found convenient to make all the horizontal measurements from the vertical tube *ag*, deducting therefrom the length of the horizontal tube.

Exp. 43. Elevate the tube *i* so that it will be nearly vertical, and observe how much the stream falls short of reaching the orifice of the tube in the cup when the bend *g* is covered. If the stream encountered no resistances from the air, or from friction against the sides of the tube, how high ought it to rise? If to the velocity of efflux from the orifice *h* there should be added the velocity which is lost in consequence of resistances, how would the sum compare with the velocity which a stone would acquire in falling a distance equal to that from the surface of water in the cup to the tube *h*?

EXPERIMENTS WITH THE "SEVEN-IN-ONE APPARATUS."

Exp. 44. Suspend the instrument, Fig. 4, from some convenient support, and rarefy the air within it by suction with the mouth; a weight of 20 lbs. ought to be easily raised. This weight, added to a probable friction of about 15 lbs., gives 35 lbs. as the unbalanced pressure exerted by the outside air on the piston.

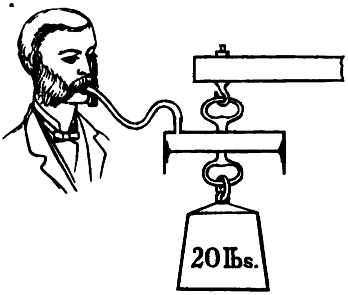

Fig. 4.

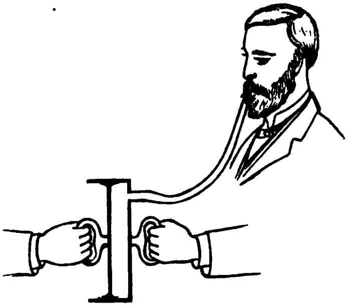

Fig. 5.

Exp. 45. Push the piston quite into the cylinder, and close the stop-cock, and let a person grasp each of the handles and attempt to pull the piston out. It is apparent that in his attempt he creates a vacuum, and few will be found strong enough to draw the piston out. This constitutes a most interesting modification of the classical *Magdeburg Hemispheres*, but with this important advantage, that it produces a self-created vacuum (the harder the pull the higher the vacuum), and requires no air-pump.

Exp. 46. Let a person alternately blow and suck air through the rubber tube (Fig. 5), and he will find it difficult to resist the forces (what forces?) tending to move the piston.

Exp. 47. Does the weight which is raised correctly represent the lung-power exerted, or is it a case similar to that in which a force is applied to the long arm of a lever?

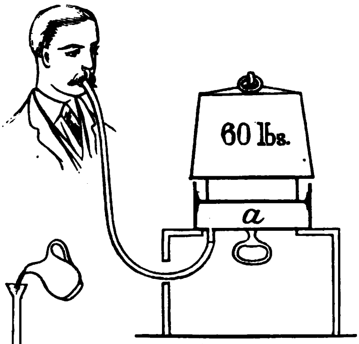

Fig. 6.

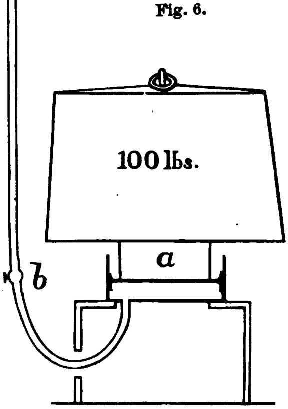

Fig. 7.

Take a glass tube about 6^{dm} long and 5^{mm} bore, bend it into a U-shape; pour into it mercury so that it will stand at a depth of about 15^{cm} in both arms; blow into one arm, and the mercury will rise in the other arm. Measure the hight of the upper surface above the lower; the weight of a column of mercury of an equal depth and the same diameter as the bore of the tube represents the lung power exerted. With a straight tube of the same bore, measure out such a volume of mercury and weigh it.

Exp. 48. Remove the handle from the piston, invert the instrument, place on the piston a block of wood, as in Fig. 6, and on the block a weight, and support the whole on a box. Blow into the instrument, and a heavy weight may be raised. The instrument thus becomes a *pneumatic bellows*.

Exp. 49. Connect with the rubber tube by means of the stopcock another rubber tube, so that the whole length shall be

12 feet (Fig. 7). Elevate the tube, insert in the upper extremity the funnel-shaped brass mouth-piece, and pour water down the tube, and a heavy weight may be raised by hydrostatic pressure, and thus the instrument becomes a *hydrostatic bellows.*

TRIBOMETRIC MEASUREMENTS.

Provide an oak plank 2^m long, 25^{cm} wide, 5^{cm} thick, planéd smoothly on one side; also several sleighs with smooth surfaces, as follows: *A*, an oak plank $14^{cm} \times 14^{cm} \times 2.5^{cm}$; *B*, ditto, $28^{cm} \times 14^{cm} \times 2.5^{cm}$; *C*, a pine plank of same dimensions as *A*. Attach a pulley to the middle of one end of the plank in such a manner that a string fastened to one end of a sleigh and passing over the groove of the pulley will be parallel with the surface of the plank. Provide also two pails and a half bushel of sand.

Exp. 50. Place the plank in a horizontal position, about 2^m above the floor, and on it sleigh *A*, near the end opposite the pulley. Place one of the pails on the sleigh containing sufficient sand to cause, together with the weight of the plank and pail, a pressure between the sleigh and plank of (say) 10 lbs. Carry the string attached to the sleigh over the pulley, and from the free end suspend the other pail. Place sand in this pail, regulating the amount, so that, on starting the sleigh with a light blow, it will move along the plank with approximately uniform velocity. The weight of this pail, together with the sand, is the measure of the friction *F* caused by the given pressure *P*.

The ratio of the friction to the pressure is called the coefficient of friction; *i.e.*, $\frac{F}{P} = C$, the coefficient of friction.

Exp. 51. Make $P = 20$ lbs., and ascertain *F* by experiment. Find the coefficient of friction, and compare it with that obtained in the preceding experiment.

Exp. 52. Repeat the last experiment, using sleigh *B*, making *P* the same as before. How does the amount of surface in contact affect the amount of friction?

Exp. 53. P remaining the same, find the coefficients of friction when the fibres of the sleigh are parallel to the motion, and when they are perpendicular to the motion.

Exp. 54. With $P = 20$ lbs., and using sleigh C, ascertain the coefficient of friction between oak and pine.

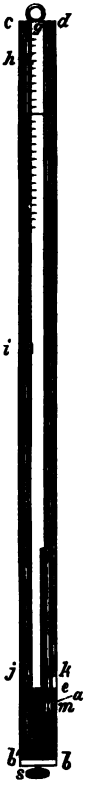

Fig. 8.

Exp. 55. Ascertain the friction of motion and of repose, *i.e.*, the value of F necessary to keep up uniform motion, and the value of F just sufficient to overcome the state of rest.

Exp. 56. Make the suspended weight great enough so as to produce a slightly accelerated motion, and determine whether the acceleration is uniform. If it is uniform, we must conclude that the amount of friction is independent of velocity.

SIPHON BAROMETER.

Exp. 57. With the blow-pipe flame close one end of a glass tube whose internal diameter is 6^{mm} or 7^{mm}, and length about 1.20^{m}. Apply the flame so as to make a slight constriction about 20^{cm} from the open end; then about 6^{cm} or 7^{cm} farther, so as to bend the tube into U-form, the open arm being parallel to the closed arm, and distant from it 2^{cm}. If this be filled with mercury, with care lest any air-bubbles remain entangled, the difference of level ef between the two columns will be about 76^{cm}, being greater or less in proportion to the atmospheric pressure.

Upon a strip of wood whose length bc is 1^{m}, and breadth dc is 5^{cm}, fasten a yard-stick eg or a metre-stick; the latter is preferable, and should be placed midway between the two edges of the strip. Any smooth strip of wood will do, if cut squarely off at the bottom e, and a mark f be drawn across at a distance of 76^{cm} from e. On each side of this mark the edge may be graduated in millimeters for a distance of 5^{cm} or 6^{cm}.

Place the glass tube against the broad strip so that its lower curved portion may enclose the graduated strip. Secure it loosely with little loops of tinned sheet-iron, *h*, *i*, *j*, *k*, so that the tube may slide easily past the fixed graduated strip. At the lower end fasten a little block of hard wood *bb'*, projecting enough to form a ledge on which the bend of the glass may rest. Through a hole in this ledge pass a tight screw, with milled head and smoothly-rounded end. The block serves as a nut, and the bend of the glass rests on the rounded end of the screw. The glass may be therefore lifted or depressed by turning the screw.

Adjust the quantity of mercury so that the level in the open arm shall be tangent to the line forming the bottom of the graduated strip at *e*. This line may be extended across *el*, on paper, the lower half *em* being made black with ink, the upper half *ek* white, so that the hight of the curved surface of mercury at *e* can be accurately adjusted against a sharply-defined background.

Finally, a screw-eye at *g* may be inserted, so that the instrument may hang vertically.

If the atmospheric pressure should decrease, the column at *f* falls and at *e* rises. By a few leftward turns of the screw, the tube and its contents sink down until *e* is brought opposite the fixed zero-point. If the pressure increases, a few rightward turns bring *e* up to the zero-point. After adjusting at zero-point, the hight of the barometric column is read in the neighborhood of *f*.

HEAT.

Exp. 58. *Conduction.* Lay a thin gelatine card on the palm of the hand. The card being a poor conductor of heat, the lower surface will become more heated than the upper; consequently it will expand more, and bend so that the ends will meet. If it is placed upon a cold surface it will bend in the opposite direction. Glass (especially a variety called lime-glass) ware, when suddenly subjected to great heat, tends to bend in the same manner, but, being only slightly flexible, it is liable to crack, especially if it is thick.

Exp. 59. Wrap the bulb of the thermometer in muslin, and dip it into ether; allow it to remain until the mercury has acquired the temperature of the liquid, then take it out and note the fall of temperature.

Exp. 60. Take a deep beaker of about 800^{cc} capacity three-fourths full of cold water. Pour gently on its surface linseed oil at about 110° C., to the depth of about one inch, and suspend several thermometer bulbs at different depths in the liquid, and notice the slowness with which heat is conducted through the liquid.

Exp. 61. Cut off the nose of a glass funnel of about 800^{cc} capacity. Pass the stem of an air thermometer (having a small bulb) down through the funnel, leaving the top of the bulb about five-sixteenths of an inch below the surface of a card laid temporarily across the edge of the funnel. Fill the space between the neck of the funnel and the stem of the thermometer with sealing-wax, so as to become water-tight. Support the whole in a ring of a ring stand. Partially fill the stem of the thermometer with water colored with ink, and pour cold water into the funnel until its surface is one-fourth of an inch above the bulb. Then carefully pour ether upon the surface of the water until the funnel is full, being careful that none runs down the side of the funnel. Ignite the ether with a match, and notice the slowness with which the heat from a very hot fire penetrates the quarter of an inch depth of water, so as to affect the sensitive thermometer.

Exp. 62. *Convection.* Fill a thin glass flask of about 400^{cc} capacity with hot water deeply colored with ink. Stopper the flask with a cork pierced with a glass tube having a bore of about 5^{mm} diameter. Close the exposed end of the tube with a finger, and thrust the flask to the bottom of a tub or pail (preferably a deep glass jar) filled with cold water, and withdraw the finger. A stream of colored liquid will ascend for a long time from the flask to the surface of the water in the larger vessel.

Exp. 63. Fill a glass flask as before, invert, thrust the neck into water, and withdraw the cork. No convection takes place downward.

Exp. 64. With a porte-lumière and lens, project a large circle of light on a distant screen, and suspend in the path of the beam, beyond the focus of the lens, a red-hot metallic ball or a candle flame.

Exp. 65. Lay a block of ice across the back of two chairs, and over it pass a piece of fine iron wire, the ends of which have been twisted together. From the wire suspend as great a weight as the wire will support, say 25 to 50 lbs. It is evident that since the extent of ice surface on which a fine wire will press is small, the pressure *per square inch* on the ice must be very great. The consequence is that just beneath the wire the ice is melted, and the wire drops down a little. As soon as the wire falls, however, the water about it is relieved from pressure, and immediately freezes. In a short time, therefore, the wire passes completely through the ice.

Exp. 66. Take 200^{g} of fine dry ice chips or snow at 0° C., and an equal weight of water at 80° C.; pour the latter upon the former, and with a glass or wooden rod stir and melt the solid as quickly as possible; and as soon as all is melted, take the temperature. The experiment should be conducted in a room whose temperature is as nearly 0° C. as possible.

Exp. 67. Take about a tablespoonful of water in a test-tube, twist around the tube near the bottom a wire for a handle, surround the tube with a freezing mixture, and freeze the water; or a lump of ice may be dropped into the tube, and a pebble-stone or coil of wire placed on top of it to keep it down. Then pour cold water into the tube, nearly filling it, and hold the tube in a flame (as in Exp. 5, p. 143, Physics), and boil the water at the top without melting the ice.

Exp. 68. Place a beaker of water at about 40° C. under the receiver of an air-pump, and exhaust the air, and cause the water to boil.

Exp. 69. Repeat the last experiment, causing the water to boil for about ten minutes; at the same time expose to the temperature of the same room in another beaker an equal quantity of water at the same temperature. At the end of the operation take the temperature of both waters. Account for the difference in temperature.

Exp. 70. Do up a piece of writing-paper into a cone shape, gumming the edges smoothly down. Fill it with water, and place it in a loop of wire, and hold it in a Bunsen or spirit flame, and boil the water. The paper will not be charred, for a temperature of 100° C. is not sufficient.

Exp. 71. Paste a strip of paper smoothly around a cylinder of brass or copper, and another strip around a wooden cylinder. Hold them in a Bunsen or spirit flame. The paper on the wooden cylinder will soon become charred, but the paper on the metallic cylinder will not char for several minutes because the metal conducts the heat away so rapidly from the paper that it is not readily raised to the ignition point.

Exp. 72. Take two air thermometers, the bulb of one of them blackened with soot from a candle flame. Let the liquids in the two stems stand at the same hight. Expose each bulb for the same length of time to the sun's rays.

Exp. 73. Repeat the last experiment, except that a convex lens be interposed, and the bulbs placed in the focus of the rays.

Exp. 74. Take two thermometers like those used in the last two experiments, and fill the bulbs and a portion of the stems of each with hot water, and set them, stems upward, in a cool place, and observe by the fall of liquid in the stems which cools more rapidly.

Exp. 75. Partially fill a bladder or the spherical rubber ball furnished for pneumatic experiments with cold air, and place it near a hot stove for a time.

Exp. 76. Fill a test-tube of about 2^{cm} diameter with water. Insert, water-tight, a stopper pierced with a small glass tube, crowd the stopper into the test-tube so that the water will rise in the tube four or five inches. Surround the test-tube with a freezing mixture, and watch for the maximum density of the water, which is reached when the water in the tube reaches its lowest point. Subsequently the water will rise in the tube. This phenomenon is best observed through a telescope a short distance away. Or it may be projected by a porte-lumière on a screen.

ELECTRICITY.

INTRODUCTORY EXPERIMENTS.

EXPERIMENT 77. Place a (tangent)[1] galvanometer so that the needle at both extremities points to zero on the graduated circle; in other words, so that the coil will lie in the magnetic meridian. Connect the wires leading from a (Daniell or Bunsen) voltaic cell with the screw cups of the galvanometer. This is called, technically, "introducing a galvanometer into the circuit," inasmuch as the galvanometer now forms a part of the circuit, and the current is obliged to pass through it. When the needle *comes to rest*, note the angle of deflection as indicated by the number of degrees to which either extremity of the needle (if there is a difference in the readings, take a mean of the two) points. Observe at which screw cup the current enters the galvanometer, and at which it leaves it, and the direction of the deflection.

EXP. 78. Remove the wires from the screw cups, and, by crossing them (if the wires are not insulated, they should not touch each other), insert each wire in the screw cup opposite the one to which it was before applied. The deflection of the needle is reversed. This shows that the direction of the current through the galvanometer has been reversed. But, by inspection of the circuit, it will be seen that *the current is reversed in only this portion of the circuit.* Can you invent some arrangement by which the current can be reversed in a portion of the circuit more conveniently than by shifting the wires from cup to cup? Such a device would be called a *pole changer* or *commutator.*

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[1] Two needles are furnished with each galvanometer: one is *astatic*, and when this is used the instrument will be called an *astatic galvanometer;* when the other needle is used it will be called a *tangent galvanometer.*

Exp. 79. Take a voltaic cell, constructed in the manner described in § 151 of the Physics, first using an unamalgamated zinc. Connect each of the wires attached to the strips of copper and zinc with the galvanometer. Thrust them into the dilute sulphuric acid, holding them quietly in it and at a constant distance apart. Watch for a few minutes the deflection of the needle.

Exp. 80. Repeat the last experiment, using an amalgamated zinc. The deflection diminishes in time, but not so rapidly as in the last experiment.

In the preceding experiment the local currents, established by the impurities in the zinc, did not pass through the main circuit; consequently the main current was very weak. In this experiment, the entire current developed in the battery passes through the main circuit. The *falling-off* of the current which followed the first introduction of the strips into the liquid was due to the *polarization* of the strips.

EFFECTS OF CONDUCTORS OF DIFFERENT LENGTHS, SIZES, Etc.

Exp. 81. Introduce into the circuit with the galvanometer Spool 1 (see Catalogue of Apparatus), containing 32 yards of No. 23 copper wire, in such a manner that the current from the battery will pass through both the galvanometer and the spool; it matters not which it passes through first. To make certain that the connections are all properly made, it is best for a young experimenter mentally to trace the current from the carbon successively through every connection and instrument, back to the zinc of the battery, and see that a suitable path is opened for the current. The screw cups on each side of a given spool are to be used to send a current through that spool.

A deflection smaller than before ensues. The circuit is now 32 yards longer than before, and the result is a weakened current, resulting from increased resistance. Compare the currents in this experiment with the current in Exp. 77, by comparing the tangents of the degrees of deflection as obtained from Table of Tangents, p. 403, Physics. Thus, suppose that the deflection in the first experiment was 84° and in the latter 80°: the tangent of $84° = 9.51$; of $80° = 5.67$. $9.51 \div 5.67 = 1.6 +$, *i.e.*, the former current is about 1.6 times the latter.

Exp. 82. Substitute Spool 3, containing 16 yards of No. 23 copper wire, for Spool 1. A larger deflection is obtained than in the former experiment, and you learn that, other things remaining the same, the current varies inversely with the length of the circuit. It is proper to observe here, that if the *entire* circuit were made half as long, in other words, if the entire resistance in the circuit were reduced one-half, the current would be exactly doubled. In this case, only a portion of the circuit is reduced one-half; consequently, the current is not quite doubled.

Exp. 83. Substitute for Spool 3, Spool 2, containing 32 yards of No. 30 copper wire. A smaller deflection is obtained than with Spool 1, which contains the same length and kind of wire, but of greater diameter. Conclusion?

Exp. 84. Obtain the deflection with Spool 4, containing 16 yards of No. 30 copper wire, alone in the circuit, and compare the current with that obtained in Exp. 83.

Exp. 85. Obtain the deflection with Spool 5, containing 16 yards No. 30 German silver wire, alone in the circuit. Compare the current with that obtained in Exp. 84. Conclusion?

INTERNAL RESISTANCE.

Exp. 86. Take a strip of copper and a strip of amalgamated zinc such as used in Exp. 79. Connect the free extremities of the wires with the screw cups of the galvanometer, and introduce the two strips into the liquid, keeping them about half an inch apart. Note the deflection of the needle. Raise the strips half way, and three-fourths way, out of the liquid, noticing the corresponding deflections. As the strips are raised out of the liquid, the size of the liquid conductor between them, in other words, the transverse section of the portion of the liquid between them, is diminished, and the result is an increase of resistance corresponding to the increase of resistance which attends the reduction of size of a solid conductor, as seen above.

Exp. 87. Once more place the strips as at the beginning of the previous experiment, then gradually separate the strips as widely apart as the tumbler will admit, and note the corresponding changes in deflection of the needle. The farther the strips are separated the less the deflection, showing that the effect of increasing the length of a liquid conductor is the same as increasing the length of a solid conductor.

MEASURING RESISTANCES.

Exp. 88. Measure the resistance of the wire on each one of the spools as follows: First, introduce a spool into the circuit with a galvanometer, and get the deflection. Then remove the spool, and introduce in its place the rheostat or set of resistance coils. Place the three switches *A*, *B*, and *C* (Fig. 9) each on the zero butt of its corresponding graduated arc. The circuit will then be closed through this instrument, as may be seen by the deflection of the needle of the galvanometer. If one of the switches does not at any time rest on a butt, the circuit will be broken. By comparison with the deflection when the rheostat is not in circuit, it will be seen that when all the switches are on the zero butts there is no appreciable resistance introduced into the circuit through the

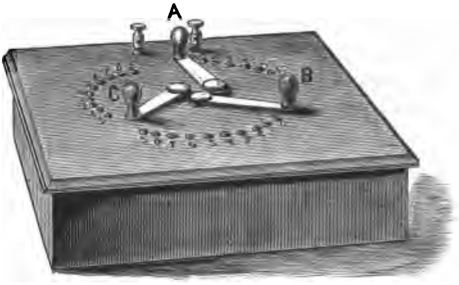


Fig. 9.

rheostat. Now you are to aim to obtain the same deflection of the needle of the galvanometer that you obtained when the given spool was in circuit. This is done by introducing through the rheostat a resistance exactly equal to the resistance of the wire of the spool. You find on the upper surface of the box which encloses the coils (and thus protects them from injury) three graduated arcs, one extending from 0.1 ohm to 0.9, the next from 1 ohm to 9 ohms, and the last from 10 ohms to 100 ohms. As in weighing with a balance beam and a set of weights of three denominations, you put into one of the pans weights until you succeed in balancing the article to be weighed, and then add together the weights of the three denominations to get the total weight, so you introduce resistances into the circuit by moving one and another switch up their respective scales until the required deflection is obtained. Then add the resistances of the three denominations (corresponding to the tenths, units, and tens of the decimal system of notation), and the sum is the resistance of the wire and the spool. This method of measuring resistance is called the *method by substitution*. It is the most expeditious method, and for many practical purposes gives sufficiently accurate results. It is of course based upon the assumption that the E.M.F. of the battery remains constant,—a consummation, as will appear farther on, rarely *fully* realized.

Exp. 89. Introduce into a voltaic circuit through a rheostat a known resistance r, and obtain a deflection a. Then introduce in place of the rheostat a wire whose resistance r' is to be measured, and get deflection a'. Since the tangents of angles of deflection are proportional to the currents, and currents are inversely proportional to the resistances, we have

$$\tan a' : \tan a :: r : r';$$

whence

$$r' = \frac{r \tan a}{\tan a'}.$$

From this formula compute the resistance of the wire. Verify the result by the "method by substitution."

Exp. 90. Measure the resistance of Spool 4, containing 16 yards of No. 30 copper wire; measure also the resistance of Spool 2, which contains the same kind of wire; calculate the length of the wire on the latter spool as follows:

$$r : r' :: l : l', \text{ whence } l' = \frac{r'l}{r},$$

in which l is the length of the wire in Spool 4, and r its resistance, r' the resistance of Spool 2, and l' the length of wire to be found.

Exp. 91. Connect in series from five to ten Bunsen cells, and introduce into the circuit with the battery through a rheostat a resistance of (say) 50 ohms. Note the deflection. Remove the rheostat, insert the two poles in metallic handles such as are used in giving shocks. Let a person moisten his hands with a solution of salt in water, and grasp tightly the handles. Note the deflection, and by means of the formula given in Exp. 89, calculate the resistance offered by the person's body.

Exp. 92. *Measure the resistance of a galvanometer* as follows. Introduce another galvanometer into the circuit with the galvanometer whose resistance is to be measured, and note the deflection of the needle of the former galvanometer. Substitute for the latter galvanometer the rheostat, and measure the resistance in the same manner as you would measure any other resistance.

Exp. 93. Measure the resistances of a voltameter, a piece of platinum wire, electro-magnets, either separate from other apparatus or such as constitute parts of apparatus, such as the electro-magnet of a telegraph sounder or a relay.

Exp. 94. Take about 1^{m} of No. 30 iron wire, wind it into a coil about 1^{cm} in diameter, and as close as possible without allowing the turns to touch one another. Introduce the coil into a circuit with a galvanometer, and note the deflection. Then heat the coil very hot by applying Bunsen flames along its length, and note the diminution of current owing to increased resistance.

MEASUREMENT OF SPECIFIC RESISTANCES.

Exp. 95. Take two wires of the same size and different material; *e.g.*, copper and platinum, or copper and iron; get the deflection with one of them (*e.g.*, the iron) in circuit, then replace it by the other, and carry one electrode of the battery along its length until the same deflection is obtained. The ratio between their lengths will express the ratio between their specific resistances.

Exp. 96. Take two wires of different substances and different sizes; determine the lengths which have equal resistances. Find, by a wire gauge, or micrometer screw gauge, the diameters of the wires, and then ascertain the ratio of their specific resistances by the formula

$$s\frac{l}{q} = s'\frac{l'}{q'},$$

in which s and s' represent their respective specific resistances, l and l' their lengths, and q and q' the areas of their cross sections or squares of diameters.

EFFECT OF CORRODED CONNECTIONS.

Exp. 97. Find (they are usually not difficult to find) some piece of electrical apparatus which has a rusty or corroded connection, such as rusty screws of screw-cups, either connected with the battery or other apparatus. If these cannot be found, select a wire which has become corroded at one or both ends by exposure to acid fumes. Introduce this corroded connection into the circuit with the galvanometer, and note the deflection. Now clean all the rusty connections with a fine file, fine sand- or emery-paper, or by scraping them with a knife, and once more send the current through the same apparatus. The deflection is now greater than before. Introduce through a rheostat a resistance sufficient to give the same deflection as at first, and thus measure the resistance caused by the corroded surfaces of contact. *Beware of corroded connections.*

JOINING CELLS IN OPPOSITION.

Exp. 98. Take two cells as nearly alike as possible, connect the zincs of each cell with each other by a short copper wire, and the two carbons with the galvanometer. There is either no deflection, or, at most, a very small deflection. This is called *joining cells in opposition.* Here the tendency of one cell to produce a current in a certain direction is counterbalanced by the tendency of the other cell to produce a current in the opposite direction, and no current flows, provided the E.M.F, of both are equal. If the E.M.F. of both are not equal, then there will be a current proportionate to their difference.

ELECTRO-MOTIVE FORCE.

Exp. 99. Connect, in opposition, two cells of the same kind but of different sizes; *e.g.*, a quart cell with a gallon cell; or, which amounts to the same thing, lift up the zinc or the carbon, or both, of one of the cells, thereby diminishing the immersed part of one of the cells; no deflection ensues. It thus appears that a large cell has no greater power to produce a current than a small cell; *i.e.*, *the E.M.F. of battery cells does not depend upon their size.*

Exp. 100. Connect, in opposition, two cells of different kinds; *e.g.*, a Bunsen cell and a Daniell cell; a deflection ensues, showing that the E.M.F. of the two cells is different, and that *the E.M.F. of voltaic cells depends upon the material used.*

MEASUREMENT OF ELECTRO-MOTIVE FORCE.

Exp. 101. Measure the E.M.F. of a voltaic cell as follows: Take, for example, a Bunsen cell, and connect in opposition with it a Daniell cell, and introduce into the circuit with this combination a galvanometer. There will be a deflection of the needle. Add other Daniell cells, one at a time, in series, in opposition to the Bunsen cell, until there is no deflection, or only a slight deflection. Inasmuch as the E.M.F. of the Daniell cell is (about) 1 volt, the E.M.F. of the Bunsen cell will be approximately as many volts as the number of Daniell cells required to neutralize it.

Exp. 102. *Measure E.M.F. by method of equal deflections,* the standard cell being E, the one to be compared being E'.

Take the deflection of E and call it R; then take the deflection of E' and call it R', adding resistance to make the deflection the same. Then

$$E' = E\frac{R'}{R}.$$

Exp. 103. *Measure E.M.F. by comparison.* Call the E.M.F. of two batteries E and E'; join them up successively in circuit with the same galvanometer, and, by varying the resistance, cause them both to give the same deflection; their forces will then be in direct proportion to the *total* resistances in circuit in each case;

or,
$$E' = E \times \frac{R'}{R},$$

when R (including that of battery, galvanometer, and the adjustable resistance) represents the resistance with E, and R' with E'.

Exp. 104. Place the cell whose E.M.F. is to be measured in circuit with a galvanometer; it produces a deflection of d degrees; then add enough resistance r to reduce the deflection to d' degrees, say 10 degrees less than before. Now substitute the standard (Daniell) cell in the circuit, and adjust the resistances through a rheostat till the deflection is d, as before; then add enough resistance r' to reduce the resistance to d'. Now, calling E the *E.M.F.* of the battery to be measured, and E' the *E.M.F.* of the standard battery,

$$r' : r :: E' : E, \text{ whence } E = \frac{rE'}{r'},$$

since the resistances which will reduce the current equally will be proportional to the electro-motive forces.

MEASUREMENT OF INTERNAL RESISTANCE.

Exp. 105. Measure the internal resistance of battery cells as follows. Take two cells which, connected in opposition as in Exp. 98, will give no current; then introduce a third cell into the circuit with these two cells and a galvanometer, and a deflection will be produced by the latter cell. Note the deflection, remove the pair of cells connected in opposition from the circuit, and in its place introduce the rheostat, and measure the resistance of the pair of cells which has been removed. One-half of this resistance is the resistance of a single cell.

Exp. 106. Put the battery in circuit with galvanometer, and note the deflection. Halve the tangent of the deflection by introducing resistance. The resistance introduced is equal to the original resistance — that of the battery and the galvanometer coil. Deduct from the resistance introduced the resistance of the galvanometer, and the remainder is the resistance of the battery.

EFFECTS OF POLARIZATION.

Exp. 107. Introduce a Bunsen cell, whose zinc is well amalgamated, into circuit with the galvanometer, and watch from the commencement the deflection of the needle for about ten minutes. The deflection will diminish somewhat during the first five minutes, and afterward remain quite constant. A deterioration of current, greater or less, due to polarization during the first few minutes of its use, takes place with the best batteries, and proper corrections should be made for the same in all experiments in electrical measurements.

Exp. 108. Connect in opposition a fresh cell with a cell which has been working from five to ten minutes, introducing a galvanometer into the circuit. A deflection of the needle shows that the E.M.F. of the fresh cell is greater than that of the other.

CURRENT THE SAME AT ALL POINTS OF A CIRCUIT.

Exp. 109. Introduce into circuit a resistance of 52 ohms (about the resistance of four miles of telegraph wire) through a rheostat; and, between the positive terminal and the rheostat, a galvanometer. Measure the current at this point, the beginning of its journey. Then insert the galvanometer between the rheostat and the negative terminal, and measure the current near the end of its journey. Finally introduce two rheostats into the circuit, and the galvanometer between them, and throw a resistance of 26 ohms from each into the circuit. Compare the results of the three trials, and determine whether they verify Law VI., page 68.

EFFECTS OF DIFFERENT METHODS OF JOINING CELLS.

Exp. 110. Take a single cell, and introduce into its circuit a resistance coil and galvanometer. By means of the coils throw a resistance of (say) 15 ohms into the circuit. Note the deflection. Introduce another similar cell into the circuit connected abreast (see § 183 of the Physics) with the first, still retaining in the circuit the 15 ohms resistance. The deflection is *very slightly* increased if at all, by the introduction of the additional cell. Find and compare the currents in the two cases, assuming that the E.M.F. of the (Bunsen) cell is 1.8 volts, and $r = 0.5$ ohm, and $R = 15$ ohms, disregarding the resistance of the galvanometer. It will be seen, both from the experiment and the calculation, that in this case almost no advantage is gained by using two cells connected abreast instead of one. By joining the two cells abreast, we virtually make one cell of double size, and thereby reduce the internal resistance one-half. But as the internal resistance of a single cell (0.5 ohm) is a small portion of the whole resistance in the circuit, the advantage gained is proportionately small.

Exp. 111. Connect the two cells *tandem*, retaining the external resistance of 15 ohms in the circuit. The deflection is now much greater than when a single cell is used in the circuit. Compare the currents in the two cases; also, compute by Ohm's law the currents in the two cases. Here the resistance of the battery is double that of a single cell, or the whole resistance of the circuit is increased 0.5 ohm by the introduction of an additional cell. But this is a small portion of the entire resistance, and is, therefore, in this case, of little consequence. On the other hand, the E.M.F. of the battery is doubled. Consequently, the current, as shown both by experiment and calculation, is nearly doubled.

Exp. 112. Introduce a galvanometer into a circuit with a single cell by means of short, thick copper wires, and note the deflection. Then connect two similar cells abreast, and note the deflection. The deflection is much increased by the introduction of the additional cell. Compute the current in each case, assuming that the internal resistance of each cell is 0.5 ohm, and the external resistance is too small to be regarded. In both cases the whole resistance of the circuit is the internal resistance of the battery. By connecting two cells abreast, we reduce this resistance one-half, and consequently double the current, as shown both by experiment and calculation.

Exp. 113. Connect the two cells used in the last experiment *tandem*, and note the deflection. The deflection is no greater (or very little greater) than that obtained with a single cell in circuit. Calculate the current in this case. By connecting the two cells tandem we double the E.M.F. of the battery. This of itself would double the current, but on the other hand we double the *resistance* of the circuit. This would counterbalance the advantage gained by an increased E.M.F.

Exp. 114. Introduce through a rheostat 4 ohms' resistance into a circuit with two Bunsen cells connected abreast. Note the deflection. Then connect the same cells abreast, and note the deflection. Compute the currents in both cases, and determine whether the results of the experiments verify your calculations.

Exp. 115. Introduce through a rheostat a resistance of 2 ohms into a circuit with six Bunsen cells connected *tandem*. Note the deflection. Remove from the circuit five of the cells, and obtain the deflection with a single cell in circuit. Connect the six cells *abreast*, and obtain the deflection. Finally, connect the six cells as a pair of triplets as follows. Take three cells and connect the three zincs with one another; also the three carbons with one another. Connect the other three cells in the same manner. Then connect the zinc of one of the triplets with the carbon of the other triplet. In connecting the triplets with each other, it is immaterial at what point of the zinc combination or the carbon combination the connection is made. For example, the copper wire which is to connect the triplets may be attached to any one of the three zincs, or to the wire which connects the three zincs, for the three zincs in the triplet are to be regarded and treated in every respect as though it were one zinc. The same is true of the carbon triplet. Compute the current in each of the four cases, assuming that the E.M.F. of each cell = 1.7 volts, and r of each cell = 0.5 ohm, the external resistance in each case being (disregarding the resistance of the galvanometer) 2 ohms. Observe whether the results obtained by calculation are verified approximately by the results obtained by experiment.

Exp. 116. Introduce a voltameter or apparatus for decomposing water into a circuit, and measure its resistance, and determine in what way a battery of two cells (Bunsen) should be connected for electrolytic purposes.

ELECTRO-MAGNETS OF VARYING RESISTANCE.

Exp. 117. Introduce into a circuit, with a single (Bunsen) cell, an electro-magnet wound with very fine wire. Measure the resistance of the electro-magnet; then introduce by means of the rheostat an additional resistance equal to that of the magnet. Note the deflection, and test the strength of the electro-magnet by applying an armature to its poles, and observing the force necessary to pull it off. Then substitute for this electro-magnet an electro-magnet wound with coarse wire, allowing the same resistance through the rheostat to remain in circuit. Test the strength of the electro-magnet as before.

Exp. 118. Introduce the electro-magnet of fine wire into circuit, without any other resistance except that of the battery. Test the strength of the magnet as in the last experiment. Then for this substitute the magnet of coarse wire, and test the strength of this magnet. Do the results of the last two experiments verify the first law of electro-magnets, page 72?

Exp. 119. Place in circuit the same magnet of fine wire as used in the last experiment, with an equal resistance through the rheostat. Introduce an additional cell connected in series with the first. Test the strength of the electro-magnet. Note the deflection produced in the galvanometer introduced into the circuit. Compare the present current with the current when a single cell was in circuit with the same resistances.

Exp. 120. Place in circuit with a Bunsen cell a telegraph key, and a sounder of low (about 3 to 9 ohms) resistance (such as furnished by the Author). The cell will work the sounder strongly. Then introduce into the same circuit with the last a relay of about 25 ohms resistance (such as furnished by the Author). The single cell will probably not work either the relay or sounder, in consequence of the increased resistance. If either works it will be the relay.

Exp. 121. Now introduce two cells connected tandem into circuit with the relay and sounder. The relay will now work, but the sounder probably will not; or, if the sounder does work, it will be only feebly. In case it does work, introduce sufficient additional resistance into the circuit through a rheostat, so to enfeeble the current that the sounder will not work, but not sufficient to prevent the relay from working. Why will the relay work and not the sounder?

Exp. 122. Take a third voltaic cell, and construct a local circuit, with the sounder in this circuit, inserting the wires of this circuit in the two screw cups of the relay that have not so far been used. Now manipulate the key in the line circuit, and this will work the relay in the same circuit; the relay working will open and close the local circuit, causing the sounder in this circuit to work.

Exp. 123. Introduce, through a rheostat, into the circuit with the relay a resistance (say) of 65 ohms (which is about the resistance of five miles of telegraph wire). Then introduce a sufficient number of cells, connected in series, to work the relay. Compute the current which works the relay, first measuring the resistance of the relay, and assuming that the r of each cell = 0.5 ohm, and that the E.M.F. of each cell = 1.8 volts.

DIVIDED CIRCUITS.

Exp. 124. Introduce into a circuit with a single cell B (Fig. 10) a galvanometer G, and rheostat R, and through the last a resistance of 4 ohms. Note the deflection. Now take a short copper wire and attach it to the two battery wires at any two points, as a and b, by winding several turns around the wire so as to make good connections. If double connectors are used, these connections may be made easily and quickly. Note the deflection, and observe that it is very much less than before. The wire which serves as a bridge between the two battery wires is called a *shunt*. Next cut the shunt wire at some point, as at G', and introduce the galvanometer at that point. Close the circuit at the point from which the galvanometer was removed, by twisting the wires together, or, better, by inserting a double connector. A deflection of the galvanometer shows that a current is passing through the shunt wire. Observe that the deflection is greater than it was when the galvanometer was in circuit with the rheostat. We thus learn that the current be-

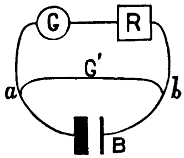


Fig. 10.

comes divided unequally at one of the two points a or b (according to the direction in which the current is flowing), and the two portions flow through the two paths open to it from that point, *the larger portion flowing through the smaller resistance.* Compare the currents in the two branches and see if the results of the experiment verify the law of divided circuits, page 69.

Exp. 125. Remove the galvanometer from the shunt wire, closing the circuit at that point, and introduce it into the circuit between the battery and point a or b. Observe that the deflection is now larger than it was before the circuit was shunted, as we might expect when we reflect that by introducing the shunt wire we virtually increase the size of the wire in the circuit beyond the points a and b, and thereby reduce the resistance of the circuit.

If a main wire is split or divided into many branches, all of equal resistance, the current will with absolute certainty and perfect exactness divide itself equally among all the branches. This fact renders the distribution of an electric current among any number of electric lamps, so that all shall be equally lighted, perfectly simple and easy, even more easy than the equal distribution of gas among a number of burners. If, however, it is desirable to make an unequal distribution, it may be very easily done by suitably varying the resistance in the different branches.

THREE METHODS OF TRANSFER OF ELECTRIFICATION.

Exp. 126. Charge a Leyden jar in the usual manner; place one ball of a discharger on the outside coating, and bring the other ball on a level with and about 8^{cm} from the ball of the jar; suspend between the last two balls by a silk thread a pith ball covered with tin or gold foil. The pith ball acted on by the electric force will vibrate between the two balls, carrying electricity from one to the other, and thus gradually discharge the jar. A transfer or current of electricity is thus kept up between the two balls in virtue of the motion (caused by the E.M.F.) of the electrified body which *conveys* the electricity as it moves from place to place. This phenomenon may be called a *current of convection.*

"Electricity *carried* through space on a charged body has exactly the same magnetic effect on a stationary magnetic needle as if it had been conducted." — Rowland.

Exp. 127. Charge the jar again and establish an electrical connection between the ball of the jar and the outside coating through a discharger. There will be a transference of electricity through the wire of the discharger, but the wire itself does not move. What takes place in the wire is called a *current of conduction.*

When a compound body is decomposed by an electric current, the mode in which the current is transmitted through the electrolyte is called *electrolytic conduction*, and is always associated with a flow of the components of the electrolyte in opposite directions.

EQUIPOTENTIAL LINES AND LINES OF FLOW.

Exp. 128. Take a sheet of tin foil *AB* about 25^{cm} square, spread out over a sheet of paper; at points x and t apply the two terminals of a battery. Then with two platinum electrodes connected with an astatic galvanometer, feel around for points c, c', c'', etc. (Fig. 11), such that when the platinum terminals are applied at any two of them the galvanometer shows no deflection. Prick through these points into the paper.

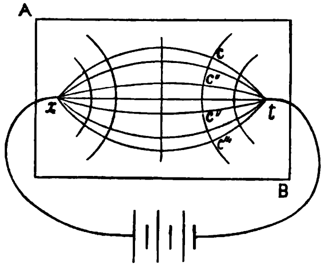


Fig. 11.

Points whose potentials are equal are called *equipotential points.* A line connecting a series of such points, as cc''', is called an *equipotential line.* As the experiment shows and the term implies, there is no current along an equipotential line.

If the direction of the E.M.F. at different points in the field are found (as may be done by suspending a very delicate elongated conductor successively over these points, the axis of the conductor placing itself in the direction of the force at each point), and if a line be drawn so that its direction at every point coincides with the direction of the electric force at that point, such a line is called a *line of force.* It is found that the direction of the E.M.F. is everywhere perpendicular to the equipotential lines, and hence the line of force everywhere cuts these lines at right angles and terminates in the electrified points or centers of force as x and t. By drawing a number of such lines as in Fig. 11, the direction of the force at different parts of the field may be indicated. Since these lines also indicate the direction in which the transfer of electrification takes place, they are called *lines of flow.*

"If from a sheet of indefinite extent we cut off a portion bounded by lines of flow, we shall not affect the electrical distribution, *i.e.*, the forms of the equipotential lines will be the same as before the sheet was cut." See Gordon's "Electricity and Magnetism," pp. 31–41, Vol. II.

INDUCTION COILS.

Exp. 129. Connect the secondary coil of an induction coil with a (tangent) galvanometer (see Fig. 170, Physics), and the primary coil with a battery. Introduce the latter coil into the former, and as soon as the needle becomes quiet, withdraw it, noting the deflections. If the deflections are too large, so as to throw the needle beyond 90°, the deflections may be reduced any desired amount by means of a shunt of suitable resistance. Then, allowing the primary coil to remain within the secondary coil, plunge an iron core within the former, and soon withdraw it, noting both deflections. Finally, introduce both primary coil and its core into the secondary coil, and presently withdraw it, noting the deflections. It will be seen that the core is a very important adjunct to an induction coil.

Exp. 130. Remove the core from the induction coil; let the primary coil remain within the secondary coil, and introduce the former together with the vibratory circuit-breaker into circuit with a single voltaic cell. Connect a pair of handles with the terminals of the secondary coil, and let a person grasp these handles, holding one in each hand. Let another person gradually introduce a core into the primary coil. The intensity of the shock will rapidly increase until it will become unendurable. The intensity of the shock can be governed by the distance the core is inserted in the coil. If the coil without the core should give painful shocks, the primary circuit may be shunted through a rheostat and any desirable resistance.

Exp. 131. Connect, by means of flexible wires several meters long, the secondary coil of a small induction coil with an astatic galvanometer, and turn it end for end in an E. and W. plane, and feeble currents will be induced therein through the influence of the earth's magnetism.

Exp. 132. Connect a telephone receiver with a sensitive long-coil galvanometer, and produce induced currents by pressing the disk of the telephone inward with the finger and allowing it to spring back.

Exp. 133. Shake the hand rapidly with the fingers spread out in front of a Geissler tube illuminated by an induction coil, and the light of the spark, being intermittent, will produce a large number of images.

Exp. 134. Select a Geissler tube contracted along the centre so that the light is reduced to a narrow, bright line. Place the tube in a vertical position, and a bi-sulphide of carbon prism a little distance from it, and project a spectrum of the light upon the screen. The spectrum thus obtained consists of several bright lines characteristic of the gases which they contain.

Exp. 135. Insulate a Leyden jar, and connect the secondary terminals of a Ruhmkorff coil with the two coatings of the jar. Lead wires of different metals from these coatings so that their extremities may be from one to two inches apart, and observe the character of the spectra produced during the discharges. The spectra produced should be characteristic of the metals used.

Exp. 136. "To show the production of induced currents in a telephone and their physiological effect. Attach the ends of the wires from a Bell telephone to the leg muscles of a frog, and speak in the telephone. The pronunciation of the word 'sucker' causes the leg to move or 'jump,' while 'lie still' has scarcely a sensible effect."

Exp. 137. Take a coil of wire of considerable size, *e.g.*, the primary coil of an induction coil (Fig. 170, Physics), and a soft iron core a little longer than the coil and about one-half inch in diameter, attach to it the poles of a battery of two cells of Bunsen, so connected as to give a strong current. Make and break the circuit by touching and separating the extremities of the wires or by a telegraph key inserted in the circuit, — the key and coil may well be in separate rooms, — and a person placing his ear near the core will hear distinct clicks ("magnetic ticks") every time the circuit is broken and closed. These *sounds proceed from molecular disturbances attending magnetization and demagnetization*. Experiments have determined also, that *iron rods are elongated on being magnetized, and retract on losing magnetism, and that heat is developed in the iron by both processes.*

Exp. 138. Lead the secondary terminals of a Ruhmkorff coil to the opposite coatings of a Leyden jar (the larger the better), and place one ball of a discharger on the outer coating and hold the other ball near the ball of the jar. The discharges will be less frequent as the jar has to be charged between each spark, but the sparks will be much more brilliant and the reports almost deafening. The jar should be placed on an insulating stand.

Instead of a single jar, several connected "in cascade" (see p. 44) may be used. All the jars in the cascade must be insulated.

EXTRA CURRENTS.

Exp. 139. Connect one of the poles of a battery with one extremity of a file as in Fig. 132 of the Physics, and draw the other pole over its roughened surface. Yellow sparks fly from the file. These are incandescent particles of iron projected into the air, caused by the fusion of the metals at the points of contact. Introduce into the circuit a helix and repeat the experiment. Now, in addition to the yellow sparks which fly from the file, there will be seen much brighter and whiter sparks following the electrode as it passes over the surface of the file. These sparks are confined to the surface of the file, and are caused by the passage of the extra currents generated at each break of the circuit (the extra current on "making" gives no spark). These sparks are of the same nature as those which pass between the secondary poles of an induction coil. Finally, insert an iron core in the helix and again repeat the experiment. The sparks produced by the extra currents are still brighter.

ELECTROLYSIS.

Exp. 140. Lay upon a metallic surface—*e.g.*, a strip of brass, copper, or tin — a piece of white paper moistened with a solution of salt, to which a few drops of ferrocyanide of potassium have been added; connect the negative electrode of a battery with the metal strip; make a positive electrode of iron by attaching to the copper wire a short piece of iron wire; move the free end of the iron wire over the paper, as if to write on it, and a blue mark will be made on the paper. See § 243, Physics.

Exp. 141. Dissolve about 1^g of iodide of potassium in 20^{cc} of water; make a starch paste by boiling a small quantity in a teaspoonful of water; take as much of the paste as will lie upon a quarter of an inch of the point of a penknife blade, and stir it in the solution. Moisten a piece of white paper with this solution; lay it upon a metallic surface; connect one of the copper poles of the battery with the metallic surface, and, with the other pole, write upon the paper as with a pencil.

HEATING EFFECT.

Exp. 142. Provide a glass flask of one liter capacity. Pass water-tight through a cork two No. 16 Kerite covered copper wires, and, close to the cork, attach to one an amalgamated zinc rod, and to the other a carbon rod, the rods being of sufficient length to reach to about half the depth of the flask. Connect the two extremities of the wire, outside the flask, by a platinum wire about 2^{cm} long and size No. 32. Introduce into the flask bichromate of potash solution enough to nearly reach the lower extremities of the rods when the flask is upright. When you would show the heating power of electricity, light gas by means of the heated wire, etc., you have only to invert the flask.

THERMO-ELECTRIC CURRENTS.

Exp. 143. Take a strip of sheet copper about 15 inches long and three-fourths of an inch wide, and a strip of zinc of the same dimensions. Lay them one upon the other, and fold over each end upon itself for about half an inch, and hammer the joints flat, so that they shall hold together quite firmly. Then separate the two strips into a somewhat elliptical or rectangular shape, as shown in Fig. 12. Cut a hole through the center of one of the strips, and pass the wire support of a magnetic needle through it. Place the band in the magnetic meridian parallel with the needle. Direct a flame against one of the junctions, and note the deflection, and determine the direction in which the current traverses the band, *i.e.*, whether

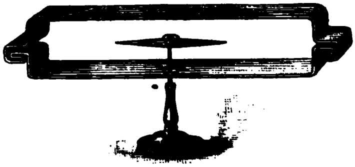


Fig. 12.

the current passes from the heated junction through the copper or the zinc strip.

Exp. 144. Attach to a (astatic) galvanometer a copper and an iron wire. It is well to let the wires rest upon pieces of ice near the galvanometer. Join the free extremities of the wires, and apply a Bunsen or spirit flame at the junction. A current is established, and the E.M.F. continues to increase till the temperature of the junction is about 284° to 300° C.; then, on raising the temperature higher, it begins to decrease, and, finally, is reversed, as is shown by a reversal of the deflection.

MAGNETISM.

Exp. 145. Heat red-hot an iron ball, and suspend it by a brass or copper wire. Bring a pole of a powerful electro-magnet near to the ball, and the latter will not be attracted. Keeping the magnet in the same position, wait until the ball has cooled, and, when sufficiently reduced in temperature, it will be attracted. This shows that iron cannot be magnetized when red-hot.

Exp. 146. Hold a soft-iron rod about 1^m long in the same position as that taken by a dipping-needle. Suspend a small magnetic needle, and bring it near the end of the poker which points downwards. The N. pole of the needle will be repelled, and its S. pole attracted, showing that this end of the poker is a N. pole. Pass the needle upwards close to the poker, and its S. pole will continue to be attracted until the middle is reached, after passing which the needle will turn round, and its N. pole will be attracted; and so onwards to the upper end of the poker, which we say has been magnetized by the *inductive action* of the earth.

Exp. 147. *Effect of percussion.* While in the position mentioned in the last experiment, strike the end of the poker several times with a hammer. This percussion will be found to have conferred *coercive force* upon the poker, which now retains its magnetism in any position.

Exp. 148. *The earth's magnetic force directive and not translative.* Float a small magnetic needle, fixed horizontally to a cork, on water. The needle will point nearly N. and S., but will not float towards the north. This is owing to the great distance of the earth's magnetic poles, which are both attracting and repelling the needle. The attraction and repulsion being practically equal, there results only a rotation, and no motion of translation. The two forces act as a *mechanical couple.*

EXPERIMENTS WITH LEYDEN JARS.

Exp. 149. Charge the jar by grasping the outer coating with the hand, and holding the ball about half an inch from the prime conductor. When the sparks cease to pass from the conductor to the ball, the jar is charged.

Exp. 150. Place a charged jar on an insulating support, and touch with a finger the ball, keeping the other hand away from the outer coating. A faint spark will pass from the ball to the finger. Now touch the outer coating, and a faint spark will pass from this coating to the finger. Continue touching alternately the ball and outer coating until the jar is discharged, or as long as a spark can be obtained from either ball or coating.

Exp. 151. Place a Leyden jar on an insulated support, and bring the ball near the prime conductor. Only a few sparks will pass from the conductor to the ball. After turning the machine for a time, discharge the jar, when it will be found that it contained only a slight charge, thus showing that *an insulated jar cannot be heavily charged in the usual manner.*

Exp. 152. Take a strip of leather one-half inch wide and long enough to encircle the jar. Through this strip, at intervals of one inch apart, thrust sharp pointed tacks. Bind the strip around the jar and over its outer coating, so that heads of the tacks will press against the jar. Now place the jar upon an insulating support, and it will be found that it can be easily and heavily charged.

Exp. 153. Take three or four Leyden jars, and place each horizontally on its side, on separate insulating supports. Bring the ball on one of the jars near the conductor of the machine, and the ball of a second jar near the outer coating of the first jar, and so on for the third and fourth jars. Let the outer coating of the last jar be held in the hand or connected with the earth, or, still better, connected by a chain with the negative conductor of the machine. Now, as the machine is worked, each jar will become charged. The interior coating of each jar will be charged with a different kind of electricity from that of the jar which precedes it, and will be less heavily charged than its predecessor. Each jar may be separately discharged in the usual manner, or the whole may be simultaneously discharged by first connecting all interior coatings with one another, and all the exterior coatings with one another; then, with a discharger, discharge the whole as if it were a single jar.

Exp. 154. Charge a jar from the prime conductor of an electrical machine, and, rubbing the ball over the resinous surface of an electrophorus, or a plate of glass covered with shellac, draw a figure upon its surface. Charge another jar from the negative conductor of the machine, and draw another figure across the last figure. Now sift the dust of a mixed powder composed of red lead and sulphur over this surface. The two powders will separate and arrange themselves in beautiful radiations, the red lead along the lines formed by the negative jar, and the sulphur along the lines formed by the positive jar.

Exp. 155. Charge separately, and in the same manner, several Leyden jars. Place them in a row on insulating stands, and connect them in series, after the manner of a voltaic battery whose cells are connected tandem, *i.e.*, connect the inner coating of the one with the outer coating of the next throughout the series. Then discharge the whole, by connecting the outside coating of the jar at one end of the row with the inside coating of the jar at the other end of the row. Very long and intense sparks are thus obtained.

MISCELLANEOUS EXPERIMENTS.

Exp. 156. Take 20 threads of linen each 12 inches long, and, placing them together and parallel with one another, so as to form a bundle, tie strings around the bundle 1 inch from either end. Suspend the bundle, by means of a short wire, from the prime conductor of the machine. As the machine is worked the threads will recede from each other and form a balloon-shaped figure.

Exp. 157. Let some ingenious boy cut from a cork or pitch a figure of the body of a spider, attaching to it linen threads about 1½ inches long for legs. Suspend the spider from some support by means of a silk thread. Charge two Leyden jars, one with negative and the other with positive electricity. Place the two jars near each other on a table and bring the spider between the two balls. It will be first attracted to one of the balls, then repelled by it and attracted by the other ball, and will continue to vibrate for a considerable time between the two balls, the legs at each end of the swing grasping the ball as if to support itself. At each swing it carries a small charge of electricity from jar to jar, and thereby gradually discharges the two jars.

Exp. 158. Take a warm, dry, wide-mouthed, shallow bell-glass or a glass fruit-dish, and rub the ball (better a point) connected with the prime conductor, while the machine is in operation, over the interior surface of the glass vessel until the interior surface becomes highly excited; then place it so as to cover a handful of pith balls lying upon a table. An animated scene will follow.

Exp. 159. Insulate an electrical machine, and connect the positive and negative conductors by a wire. However rapidly the machine is worked no charge will accumulate, thus showing that *equal quantities of + and − electricity are produced.*

Exp. 160. Steep Swedish filter paper in a mixture of equal volumes of nitric and sulphuric acids, wash in abundance of water, and dry. Lay it on a sheet of waxed paper and rub briskly with flannel or silk, and use as an electrophorus.

METAL SCREENS.

Exp. 161. Electrify a glass or sealing-wax rod and interpose between it and a pith ball a metal screen (*e.g.*, a strip of wire gauze) connected with the earth; no induction takes place. In general, *a body may be protected from inductive influence by covering it with a metal or wire gauze cage connected to earth.*

"The problem of lightning protection is to produce a space into which electricity cannot enter. If a hollow shell of copper were made, for example, a person inside would be perfectly safe, though all the lightning of the heavens were playing about him, because the electricity would pass around the outside, which would be of superior conductivity, instead of leaping across the space within. So, if a house were enclosed in a cage of copper, the lightning would pass around the cage instead of through it. The best method of protecting a house, therefore, would be to erect a central rod on the roof, from which conductors would pass to the four corners and then down to the ground. But the rods must not stop there; they must continue beneath the house, surrounding it below as above, completely enclosing the bottom as well as the roof. If it were desired to make this cage more complete, conductors might be carried from the central rod down the four sides of the house, as well as down the corners."—Rowland.

SOUND.

VIBRATIONS OF BARS.

Exp. 162. Let a carpenter prepare a pine bar as nearly uniform throughout as possible and 5 feet long, 1 inch wide, and $\frac{3}{16}$ inch thick. Cut it, as nearly as possible, into the following lengths, viz.: 3, 3.8, 4.7, 5.3, 6.5, 8.3, 10.5, and 12 inches. Arrange them side by side on a table, a convenient distance apart; commencing with the longest, raise and let drop upon the table successively each bar, and determine by the pitch of the noise (every noise has pitch) produced on striking the table the relation between the vibration period of bars and their lengths.

Exp. 163. Provide three pine bars, each 4 inches long and 1 inch wide, and respectively $\frac{3}{16}$, $\frac{6}{16}$, and $\frac{3}{4}$ inch thick. Drop them, and determine the relation between the vibration period of bars and their thickness.

VIBRATIONS OF BARS FIXED AT ONE END.

Exp. 164. Take a lath about 1^{m} long and 3 to 5^{cm} wide, and about 5^{mm} thick, lay it upon a table with about two-thirds its length projecting beyond the table, press it firmly upon the table with one hand, about 6^{cm} from the edge of the table, and with the other hand bend the free part upward and let go. Notice the pitch of the vibration. Then shorten the projecting part one-fourth, one-half, three-fourths, etc., at a time, and notice the change in pitch.

LONGITUDINAL VIBRATIONS.

Exp. 165. Grasp between the thumb and fore-finger of one hand a glass tube (about 1^{m} long and 6^{mm} in diameter) about one-third its length from one end. Place on the palm of the other hand a damp cotton cloth, and grasp the tube just below the thumb and finger and quickly draw it along the tube (the longer part) to the end. Repeat this movement several times until you obtain loud, shrill sounds as the result of *longitudinal vibrations*.

Exp. 166. Take a tube half the length of the last and produce longitudinal vibrations. The time of a complete vibration being that required for the sonorous pulse to run twice to and fro over the tube, how should the pitch of the latter compare with that of the former?

Exp. 167. Grasp in a vice, in a nearly horizontal position, a steel rod of about the same dimensions as the first glass rod, and about one decimeter from one end. Sprinkle powdered rosin on a leather glove, *e.g.*, a dogskin or kid glove, and with the rosined fingers excite vibrations by friction lengthwise the rod. Suspend by a string a small ivory ball so that it may touch the end of the rod nearest the vice. The ball will bound back and forth against the rod when it is excited, thus showing that the vibrations are longitudinal.

Exp. 168. Ascertain the wave-length in accordance with the above in wires of different substances by throwing them into longitudinal vibrations, and bringing them into unison (by varying the length) with that of a tuning-fork whose vibration rate is known. Then calculate the velocity of sound in each substance.

DIAPASONS.

Exp. 169. Take a diapason (a large tuning-fork), and by means of sealing-wax attach to the end of one of its prongs a narrow, thin piece of sheet brass, cut at one end to a fine point, or a very fine (No. 30) wire. Prepare a smoked glass by passing one of its surfaces over a candle flame. Set the fork in vibration, and draw the style over the smoked surface with uniform velocity, allowing the style lightly to touch the glass. Next draw a bow rapidly and with slight pressure at a point about two-thirds the distance from the end of the prong to the handle, and again draw the style across the smoked glass. This should give a graphical representation of the harmonic of the fundamental of the fork. If you do not succeed in this, bow the fork as before, and lightly touch with the extremity of the finger-nail a point about one-third the length of the prong from its extremity.

The sound of a tuning-fork, when set in vibration in the usual manner, contains, beside the fundamental, numerous overtones; but the interval between them and the fundamental is very great. Consequently, the overtones are very evanescent, and soon leave the fundamental practically pure. This important acoustical property is very much increased when the stem is applied to a table or resonance-box, which reënforces the fundamental at the expense of the others.

Exp. 170. Produce the fundamental note, and, while it is sounding, draw the bow so as to give the harmonic, and immediately apply the style to the smoked glass. A curve should thus be obtained, resulting from the two systems of vibrations, consisting of smaller and shorter wavers superimposed upon larger and longer ones. If you succeed in obtaining good results, and wish to preserve them, first hold the blackened surface in the vapor of boiling alcohol, to remove the grease. Then pour amber varnish over it, as when varnishing a photographic negative, and allow it to dry.

Exp. 171. Take a glass plate of the same size as a stereopticon slide. Blacken it as in the foregoing experiments, but do not apply a very thick deposit of soot, so as to make it quite opaque. Draw the style of the fork when not vibrating lengthwise the blackened surface, and about one-third its width from the edge. A simple straight line will be the result. Produce the fundamental, and draw the style across the plate parallel with the line previously drawn. Produce the harmonic alone if possible, and draw the style across the plate parallel with the last two lines. Finally, produce the fundamental and the harmonic together, and once more draw the style across the plate. Varnish the plate, and preserve it for use in projecting with the porte-lumière graphical representations of actual vibrations.

Exp. 172. Set a tuning-fork in vibration, and touch that string of a violin which is nearest its own pitch, and move it along the string to or from the bridge until a length of string is obtained which will vibrate in sympathy with the fork, when a loud sound will be given forth by the string.

SAVART'S BELL, CHLADNI'S PLATE, AND INTERFERENCE-TUBE.

Exp. 173. Set in vibration, by bowing, a Savart's bell (see catalogue of apparatus to illustrate sound), and notice the wavy sound produced as the result of interference of the fundamental with its overtones. The fundamental is produced by the division of the edge into four segments.

Exp. 174. By repeated trials determine the fundamental pitch of the bell. Produce the fundamental, and, at 90° from the point bowed, hold as near the edge of the bell as convenient without touching, one end of the open resonance-tube. The sound is strongly reënforced. Place the plunger in the remote end so as to convert it into a closed tube, preserving the same distance from the bell, and repeat; the sound is only feebly reënforced. Gradually move the plunger inward until the maximum reënforcement is obtained, and determine what part the length of an open tube a closed tube should be to reënforce a sound of a given pitch.

Exp. 175. With the same bell produce a sound of higher pitch than the fundamental, and, with the plunger, adapt the length of the closed tube to the sound.

Exp. 176. Produce the fundamental, and reënforce with the closed tube its lowest overtone.

Exp. 177. Remove the bell from its iron support, and mount in its place the Chladni's plate. Scatter evenly over its surface fine writing-sand from a wooden sand-box, such as furnished by stationers. Bow the center of one edge with a rosined bow, producing the fundamental of the plate, known by the sand arranging itself in diagonal lines, so as to divide the plate into four segments. Note that in whatever way the plate is divided, there is always an *even* number of segments formed.

Exp. 178. (*a*) Bow the plate near one of its corners. (*b*) Bow the plate in the middle of the edge next you, and, with the thumb and one finger of the left hand, damp the left edge at points one-fourth the length of the edge from each of its extremities. (*c*) Obtain a variety of figures by varying the points bowed and the points damped. Make drawings of each, note the pitch of each, and describe the method by which each was produced.

Exp. 179. Produce the fundamental by bowing the center of one edge, hold the orifices of the two prongs of the interference-tube over the *opposite* segments, and adjust the length of the tube so as to strongly reënforce the sound. Then place the orifices over adjacent segments, and at the *same distance from the plate as before*. Interference causes a destruction of sound.

Exp. 180. Produce "hydrogen tones" by introducing a flame of illuminating gas (at the narrow orifice of a glass tube) about 2.5^{cm} long into a glass tube about 0.8^{m} long and 8^{mm} bore. At a little distance from the flame rotate the mirror furnished for manometric-flame experiments. Obtain tones of different pitch, and note the appearance of the vibrating flame in the rotating mirror.

Exp. 181. Procure a tin flageolet at a toy shop. Over the mouth of the instrument slip a rubber tube, and connect the other end of the tube with a gas-tube nipple or other source of condensed air or gas of any kind. Obtain a glass tube from 10 to 15 ft. long, with a bore large enough to receive nearly the whole of the tapering flute. Turn on the gas slowly; the first sound heard will probably be the lowest sound produced by the flute reënforced by the glass tube; on turning on the gas with greater force, higher notes break forth one after another. As many as twenty distinct notes have been produced in this way. If precipitated silica is scattered along the bore of the tube, it will collect at the nodes of the tube corresponding to each tone.

Exp. 182. Allow the corner of a card to tap the edges of the siren plate as it is rotated, and you obtain all the phenomena derivable from the expensive Savart's wheel.

For other experiments in the phenomena of sound, see the admirable little volume on Sound in the Experimental Science Series, by Prof. A. M. Mayer.

LIGHT.

RADIOMETER.

Exp. 183. Light a match, and hold the flame three or four inches from a radiometer.

Exp. 184. Place a radiometer three or four feet from a gas-flame.

Exp. 185. Hold the palm of your hand about an inch from a radiometer.

Exp. 186. Find the greatest distance from lights of different kinds, *e.g.*, candle, kerosene, spirit, and Bunsen (both the light-giving and colorless) flames, and the electric light, that motion in the radiometer can be produced, and thus compare the mechanical power of the ether waves proceeding from the different sources.

DAYLIGHT PHOTOMETRY.

Exp. 187. (Pickering.) Provide a box about 6 ft. long, 1 ft. wide, and 1½ ft. deep. A wooden frame covered with black paper will answer the purpose. Cut a circular hole about 4 in. in diameter in one end, and cover it with blue glazed paper with the white side out. Let drop a drop of melted sperm-candle wax upon the center of the disk, rubbing it around with the finger so as to cover a circular space of about the size of a silver dollar. Take a lath a little longer than the box, and about two inches wide, and cut a small hole in the end of the box containing the paper disk large enough to allow the lath to pass through it into the box, leaving one end projecting from the box. Upon the end of the lath in the box mount a lighted candle. The box should be properly ventilated by holes, so that the candle may not become extinguished. Taking hold of the exposed end of the lath, push the candle so far away from the paper disk that, in a room where the intensity of light is to be measured, the paper disk will appear dark in its center. Then draw the candle slowly forward until the center appears neither darker nor brighter than the center of the disk. Measure the distance of the candle from the disk. (If the lath has a scale of inches marked off on it, the distance will be very easily ascertained by observing the portion of the lath extending from the box, and deducting that from the length of the lath.) Unity divided by the square of this distance gives a measure of the comparative brightness of the daylight under various circumstances. Carry the box into different parts of the same room, and into different rooms, and measure the intensity of the light.

Exp. 188. With the daylight photometer measure the fading of the light at twilight. Other interesting experiments may be made with the same apparatus, by observing the intensity of light during an eclipse, and by comparing moonlight, and light of the Aurora, with daylight.

MEASUREMENT OF REFRACTION.

Exp. 189. Take "a tank with platinum electrodes," such as furnished by the author for projecting "phenomena attending electrolysis." Pour water into the tank, leaving about a quarter of an inch of electrodes exposed. Prepare two paper scales long enough to extend across the glass between the brass framework, and 4^{mm} wide, making the divisions of the scale 2^{mm} each. With flour paste apply one of these scales to the external surface of one of the glass sides, parallel with and about 1^{cm} below the surface of the water. Apply the other scale above and parallel with this, and so that the lower edge of the paper will be on a level with the upper extremities of the platinum electrodes. Place the eye about on a level with the surface of the water, so that it can, without moving, see both scales. If the eye is placed directly opposite one of the electrodes, it will appear at the same point on both scales; but the other electrode will appear at different points on the two scales, and the difference will be the amount of refraction. Move the eye to different positions, and observe the amount of refraction in each. It will be still better to set up vertical wires outside the tank and view them through the liquid.

LENSES.

The lens accompanying the porte-lumière is admirably adapted to the following experiments.

Exp. 190. *To find the focal length of a convex lens.* Hold a convex lens in the sunlight, its face at right angles to the sun's rays. Behind the lens and parallel with it hold a piece of light brown paper. Move the paper back and forth until the circle of light projected upon it is smallest and brightest. The distance of the paper from the center of the lens is its focal length.

Exp. 191. In a darkened room hold a candle-flame a few feet in front of the convex lens, and behind the lens a screen of white paper or white cotton cloth. Move the screen back and forth until a distinct inverted image of the flame is formed on the screen. Measure the respective distances of the image and object from the lens; also obtain as nearly as possible corresponding dimensions of the image and object, and verify the following formula: —

$$\frac{O}{I}=\frac{d}{d'},$$

in which O represents a given dimension of the object, and I a corresponding dimension of the image, and d and d' the respective distances of the object and image from the lens.

Exp. 192. Place a convex lens facing a window, and at a considerable distance from it. Upon a screen behind the lens project a distinct image of the window-frame. Observe that the distance of the image from the lens is greater than its focal length. Carry the lens nearer to the window; the distance of the image from the lens increases. Verify the following formula: —

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f},$$

in which o and i represent the respective distances of the object and image from the lens, and f its focal distance.

Exp. 193. Hold a convex lens at a considerable distance from the window, as before; ascertain the distance of the lens from the window and from the image on the screen, and calculate its focal length from the last formula given.

Exp. 194. Look with one eye through a bi-convex lens at a piece of engineer's paper (divided into small squares) placed at its focus; with the other eye look at a piece of the same paper placed at a distance of ten inches, and determine how many squares seen with the naked eye are contained in one seen through the lens, and thus judge approximately of the magnifying power of the lens.

Exp. 195. Repeat the last experiment, using, in place of the lens, a visiting-card pierced by a pin-hole.

THE RAINBOW.

Exp. 196. Fill a glass bulb about 1½ in. in diameter (those furnished for air-thermometers answer the purpose) with a filtered solution of common salt in water. Cover the aperture of the porte-lumière with a black cardboard, so as to completely exclude the light from a darkened room. Cut a hole in the center of the cardboard of the same diameter as the bulb, and allow a circular beam of light to pass through it and also through a hole of about 4 in. diameter in the center of a white cardboard about 2 ft. square, and strike the bulb placed at a distance of about 2 ft. in front of the white cardboard. A miniature rainbow will be reflected back from the bulb upon the screen around its aperture. Any spot on the screen where red, for instance, appears, means that an eye situated at that point would see red in the glass bulb. Every other color, unless the eye was moved, would require another bulb in the proper relative position.

AFTER-IMAGES.

Exp. 197. Admit light into a darkened room by means of a porte-lumière through a slit about 1^{mm} wide, and project a bright spectrum upon a screen. Let the spectators look steadily at the spectrum for five or ten minutes; then suddenly cut off the light, and, at the same instant, turn on a gas light, and a reversed spectrum will be seen on the screen, *i.e.*, the complementary of the former colors will be seen as an after-image.

Exp. 198. Prepare a circular disk of tin 10^{cm} in diameter; punch holes about 4^{mm} in diameter equal distances (say from 3 to 4^{cm} apart) from one another in a circle within about 5^{mm} of the edge of the disk. Cut a hole in the center of the disk about 7^{mm} diameter, and place it on the spindle of the rotating apparatus. Place the disk in the path of a beam of light introduced into a dark room by a porte-lumière, and beyond the disk a lens, and focus the holes on a screen. Rotate slowly: a flickering light will be produced on the screen. Rotate rapidly, and the light will appear steady, due to *persistence of vision.*

EFFECT OF CONTRAST.

Exp. 199. On a sheet of white paper place an opaque ball, *e.g.*, a base-ball. Darken a room, and admit a small quantity of indirect sunlight through a space in one window about 1^{dm} wide. Place the paper and ball so that a shadow of the ball will be cast upon the paper. On the same side of the ball that the shadow is place a kerosene flame, at a short distance, so as to cast a shadow on the opposite side. So regulate the position of the paper and ball that the two shadows will have about the same depth. The shadow cast by sunlight will be yellow; that cast by the flame, blue. Explain.

Exp. 200. Obtain a strip of cardboard about $40^{cm} \times 6^{cm}$, and a pan of vermilion water-color pigment. With a camel's-hair brush, by repeated washes, paint a portion of the strip at one end about 6^{cm} wide very deep, so that it will appear quite dark. Then gradually grade the depth of the color up from this end toward the other end, leaving a portion about 6^{cm} wide at one end uncolored. Let the grading be so neatly and carefully done that the eye will not detect the lines of separation of the different grades. This may be effected partly by varying the number of washes, and partly by thinning the washes with water. The effect is pleasing to the eye, and the phenomenon is instructive, as the effect of different depths of the same color are plainly depicted.

Now with the same pigment paint a piece of plain white paper of uniform depth throughout, and about the same as the intermediate depth on the cardboard. Cut out of this paper circles about 15^{mm} in diameter, and paste them about 5^{cm} apart, centrally and lengthwise across the cardboard. Although all the circles have the same depth of color, they will appear, as the effect of contrast, to be of very different depths. To make the deception apparent, it is only necessary to take another strip of cardboard (or paper) of the same size as the first, cut holes about 13^{mm} in diameter, to correspond with the circles, and lay it over the first cardboard so as to conceal all but the circles, when the latter will all appear to be of uniform depth.

Exp. 201. Get papers of as great variety of colors as possible, and cut out of each squares of 6^{cm} edge. Also cut circles of 1^{cm} diameter out of the same colors, two of a kind. Place two circles of the same color upon squares of different colors, and it will be difficult to persuade yourself that the circles have the same color until you remove the circles from the colored squares and place them side by side. By many experiments verify the following

Rule:

If we surround one color with another color, the former will apparently be changed, as if some of the complementary of the latter had been mixed with it. Or, when any color of the chromatic circle (Fig. 282, Physics) is brought into competition or contrast with any other color, the former is driven farther from the latter in the circle.

In case two colors are brought into juxtaposition and there is not great inequality in their areas, the two colors mutually drive each other apart. This may be shown by placing the squares in juxtaposition. Also slip one square behind the other so as nearly to conceal one by the other. In all these experiments it is best to stand at some distance from the objects under examination.

Exp. 202. Introduce into the porte-lumière in place of a slide a green glass, having any design cut out of opaque paper pasted on it, and a black design on a green ground will appear on the screen; but on bringing another light into the room or turning up the gas, the black design will at once appear as a brilliant pink. A glass of any other color may be used, and a design of its complementary color will appear.

Exp. 203. Paint figures on a white cardboard with chrome yellow. Illuminate the card in a darkened room with a salted Bunsen flame. The figures nearly disappear. Explain.

Exp. 204. Pour a little blue coloring solution into a glass beaker or large test-tube, and place behind it a black cloth; the larger portion of color disappears. A white cloth or white paper brings out the color more strongly. Explain.

Exp. 205. Lay a piece of gold leaf on a piece of glass, and look through it at the sun. Explain the change in the color of the gold leaf.

POLARISCOPE.

Exp. 206. Remove the analyzer *A*, Fig. 293, Physics, from the polarizer, and examine light reflected from the top of a varnished table. Rotate the analyzer, and see whether the light appears equally bright in all positions. Observe whether the color of the wood and its grain is seen better in some positions than in others.

Exp. 207. Place a coin under several plates of glass, and allow a strong light to fall upon it. Examine the reflected light with an analyzer, and see whether in those positions in which the light is polarized the coin is visible.

COLOR-BLINDNESS.

Exp. 208. Fill one of the tanks accompanying the porte-lumière with a solution of sulphate of copper, and look through it at various colored objects, and you will get an approximate idea of the appearance of things to a red-blind person. Or,

Exp. 209. Darken a room, and with a porte-lumière introduce a beam of light, causing it to pass through the tank, and afterwards through the convex lens. Let the light fall upon colored objects. Colored glasses may be used. When a yellow glass is used, the condition of the spectators is analogous to that of violet-blind persons, or of those who examine colors by gas-light, which is deficient in violet.

THE TELESCOPE.

By reference to Figs. 269 and 295 of the Physics, it will be seen that the distance of the image (*ab*) formed by a convex lens (*e.g.*, the object-glass) from the lens is greater for near objects than for objects farther off. Hence the eye-glass must be slightly farther from the object-glass in viewing near objects than in viewing objects farther away.

It will be seen that the distance of the image from the object-glass is somewhat greater than its focal length. On the other hand, the eye-glass must be brought somewhat nearer the image than its focal length. Hence the distance between the two lenses is *nearly* the *sum* of the focal lengths of the lenses.

Exp. 210. Place the lens accompanying the porte-lumière (or a lens having a focal length of 8 to 12 inches) from 4^m to 8^m from a window. Mount a white cardboard, and project upon it a distinct image of the window-frame. On the side of the cardboard opposite the image write a word with pen and ink. Take a convex lens of two inches to four inches focal length, and locate it so that the writing on the card can be seen through it distinctly and much magnified. Now withdraw the card, and the image of the window-frame will be seen much magnified.

In a darkened room a candle (or better, a gas or kerosene) flame may be substituted for the window-frame.

Use eye-glasses of different powers.

Prof. Crawford suggests the use of the projecting lens of a lantern for the object-glass, and for the eye-glass a simple hand magnifying glass, and adds, that "he finds that as a rule students have most remarkably vague notions as to the functions of a telescope, and such an experiment," as indicated above, "helps to clear up their ideas."

Exp. 211. Provide a white card 10^{cm} long and 6^{cm} wide, rule it with ink widthwise with heavy lines 1^{cm} apart, number the lines from bottom upward with plain figures, and place it in a vertical position on a black background with lines horizontal. At a suitable distance, say from three to eight rods, look at the card with the right eye through a telescope, focusing it so that the lines and figures can be distinctly seen. Then look at the card with the naked left eye, bring the image seen with the naked eye and the magnified image so that the adjacent vertical edges touch, and their lower edges coincide, measure the hight of the former on the latter by means of the numbered lines. The hight H of the larger image ($H = 10$) divided by the hight h of the smaller image will give the magnifying power m of the telescope; that is

$$m = \frac{H}{h}.$$

Exp. 212. Ascertain the focal lengths F and f of the object-glass and eye-glass; then

$$\text{the magnifying power } m' = \frac{F}{f}.$$

It will be found that m and m' are nearly equal in value. Why, if you use different eye-glasses (f) with the same object-glass (F), do you obtain different magnifying powers?

Exp. 213. Allow sky-light to pass through the telescope and form a distinct image of the object-glass on a white screen held at a suitable distance from the eye-glass. The diameter of the object-glass, divided by that of the image, is the magnifying power of the microscope.

Exp. 214. Determine by the first method described above the magnifying power of opera-glasses, looking at a card with one eye through one of the cones and at the same card with the other eye naked.

EXPERIMENTS WITH THE PORTE-LUMIÈRE.

The following experiments are intended to be supplementary to those contained in Dolbear's invaluable work on the "Art of Projection."

Exp. 215. Introduce a horizontal beam of light into the darkened room. Place a table so that its top will be from five to ten inches below the beam, and on the table in the path of the beam place the lens, and on the opposite wall or screen will be projected a large circular field of light. Place an ordinary stereopticon slide in the slide-holding disk. Move the lens back and forth until a distinctly-defined image is formed upon the screen. See Fig. 268, Physics.

Exp. 216. Introduce the disk with $\frac{1}{4}$ inch aperture. On the screen will appear several overlapping circles of light, illustrating in an interesting manner multiple reflection (Physics, p. 343).

Exp. 217. Cut small holes of triangular, square, and other shapes in pieces of cardboard, and cover the aperture of the porte-lumière. The image of the sun projected upon a distant screen in every case is round, *i.e.*, it is independent of the shape of the hole. (See Deschanel's "Natural Philosophy," ¶ 683.) Now interpose the lens.

Exp. 218. Place the disk *a* (Fig. 13) with adjustable slit in position, and in the path of the beam and at a distance from the slit about equal to its focal length, the lens *l*, and at a distance of 2^m to 4^m from the lens, a screen *s* about 1^m square. Focus the slit upon the screen, and then interpose the bisulphide of carbon prism p about 8^{cm} in front of the lens, and move the screen so as to receive the spectrum, as at s', preserving the same distance from the prism. Rotate the prism slowly on its axis until at least 15 to 20 dark lines are seen in the spectrum. More lines may be obtained by using more prisms, so as to increase the dispersion.

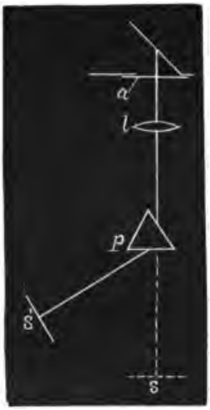


Fig. 13.

Caution. — The cement which holds the glass sides on the metal frame of these prisms is insoluble in bisulphide of carbon, but is soluble in water; hence the latter liquid should never be used in these prisms.

Exp. 219. Cover the disk of 1 inch aperture with coarse lace or punctured card paper, such as is used for book-marks, and project interference phenomena.

Exp. 220. Project the phenomenon illustrated in Fig. 257, Physics.

Exp. 221. Project the piece of glass used in the last experiment, and rotate it on its longest axis. In certain positions the light will be intercepted by total reflection, and a deep shadow cast upon the screen.

Exp. 222. Fill a small test-tube, about 6^{mm} in diameter, with water, and project it upon the screen. Only a very narrow line of light will succeed in passing through the tube. Fill one of the tanks which accompany the porte-lumière with water, and thrust the tube into the tank. The water in the tank will correct the refraction, except that produced by the glass tube.

Exp. 223. Thrust an empty tube into the water-tank.

Exp. 224. Thrust a tube filled with bisulphide of carbon into the water-tank.

Exp. 225. Make a saturated solution of sulphate of zinc, and half fill a tank with the solution. With a pipette carefully fill the tank with pure water. Let drop one or two drops of bisulphide of carbon into the liquid. The last liquid should float midway, partially immersed in the two liquids. Account for the many interesting phenomena.

Exp. 226. Repeat the last experiment, using bisulphide of carbon colored with iodine.

Exp. 227. Pass a beam of light through the lens; strike together two blackboard brushes, just above the light, after it emerges from the lens, so as to render visible the cone of rays with its base on the lens, also the cone of rays whose vertex is at the focus and base on the screen. The smoke from touch-paper (see foot-note, p. 278, Physics) may be used to advantage.

Exp. 228. Repeat the last experiment, intercepting a portion of the light by using the circular 1 inch aperture.

Exp. 229. Introduce in front of this, or a smaller aperture, a concave lens, and show the divergence caused by the lens.

Exp. 230. Using a small aperture, introduce a small beam of light, and reflect it, by means of a mirror, into different parts of the room. Explain why the angle which the reflected beam makes with incident beam is double that which the incident beam makes with the mirror. Explain why the spot of light thrown upon the walls is usually much elongated in one direction.

Exp. 231. Move a white screen slowly back and forth through the foci of the different colors produced by the lens, and observe the effects of chromatic aberration. Observe that the red rays have their focus furthest from the lens.

Exp. 232. Mix lamp-black with French polish, and thin it with spirits of turpentine. With a camel's-hair brush apply a coating to a slip of glass. Apply other coatings as fast as it becomes dry until the glass becomes quite opaque. With the point of a penknife blade draw on the glass any designs or diagrams which you may desire to project.

Exp. 233. Remove the mirror of the porte-lumière, and introduce the disk with half inch aperture. Inverted images of the landscape toward which the window is directed will be formed on the walls of the room. Persons passing by the window, at suitable distance from it, will appear walking feet upward. Let persons from a distance run toward the window, and observe the effect on the size of the images.

Exp. 234. Cover the orifice of the porte-lumière (its mirror being removed) with the lens. Behind the lens move a piece of white cardboard slowly from the lens until a distinct inverted image of a distant house, tree, etc., is projected upon the card. These experiments should be performed at such time of the day as the surfaces turned toward the lens are illuminated by the direct rays of the sun.

Exp. 235. Pour dilute sulphuric acid into the "miniature battery," and project upon the screen. A volley of hydrogen bubbles will appear to fall (because the battery will necessarily appear inverted on the screen) from the zinc rod. Connect the electrodes, and instantly the larger portion of the bubbles will escape from the copper rod, a few still escaping from the zinc. None are seen to pass through the liquid from zinc to copper.

Exp. 236. Place in position the "movable slide" to show wave-motion; draw the slip with wavy edge past the disk with parallel slits, and long lines of light will play up and down on the screen, while the wave will traverse the screen horizontally.

Exp. 237. Take the two slips with wavy edges furnished with the above apparatus; place them so that crest will touch crest, and project upon the screen. A series of elliptical areas of light extend horizontally across the screen; the vertical diameters represent the intensity of the resultant of two similar sets of waves when they so interfere that the same phases of both coincide. Gradually move the upper slip horizontally, letting it rest all the time on the upper edge of the lower slip until the crest of the upper fills the trough of the lower slip, when all the light will be cut off from the screen. The gradual narrowing of the luminous areas, until the light is entirely extinguished, will show all the results of partial neutralization by interference until the opposite phases exactly concide, when there is a complete destruction.

Exp. 238. To show the toughness of liquid films by projection, arrange the porte-lumière for vertical projection, as described, pp. 40–44, Dolbear's "Art of Projection." Over the condenser rest a shallow transparent vessel containing a solution of saponine, one part of the powder to sixty of water. The depth of the liquid may be 4 or 5^{mm} or less.

Construct a wooden frame-work like Fig. 14; the length *ab* being such that it may enclose the glass vessel. Through the uprights *bd* and *ac* are holes *e* and *f*, through which a piece of glass tubing *gh* is passed, fitting so as to rotate with slight friction. The exterior diameter of this may be 4 or 5^{mm}. Around the middle *m* is wrapped a fibre of unspun silk, whose lower end is fastened to the middle of a piece of steel needle about 2^{cm} or 3^{cm} long. Magnetize this, and let it hang horizontally over the middle of the saponine solution close to the surface. Focus so that a distinct image of the needle is formed on the screen. Bring a bar-magnet near, from side to side, and observe that the needle oscillates freely in obedience to it. Now turn the glass *gh* till the needle rests on the surface of the liquid without being immersed. Repeat the use of the bar-magnet. The needle fails to oscillate, or oscillates but slightly, being held tightly by the surface film. Again depress the needle until wholly immersed. Repeat the use of the bar-magnet. The needle oscillates freely, though slightly impeded by the viscosity of the liquid. Only at the surface is it held approximately immovable.

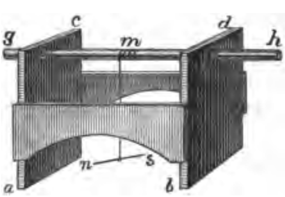


Fig. 14.

Note. The author is prepared to furnish all appurtenances necessary for vertical projection, including a tank with a plate-glass bottom.

LAWS RELATING TO ELECTRIC CURRENTS.

I. *To produce a current there must be two points at different potentials separated from each other by a resisting medium.*

To produce a continuous current these points must be maintained at different potentials. A current is an apparent transference of electricity from one point to another to produce equalization of potential.

II. *The difference in potentials between different points of a circuit varies as the resistances between the respective points.*

It is found experimentally, by measuring with a delicate electrometer, that, between any two cross-sections A and B of a homogeneous wire, in which a uniform current is kept flowing, there exists a difference of potentials, and that if the wire be of uniform section throughout, the difference of potentials is in direct proportion to the length of the wire between the cross-sections.

Suppose that A, B, and C represent consecutive points in a circuit, d the difference in potentials between A and B, and r the resistance between the same points, d' the difference in potentials between points B and C, and r' an unknown resistance between the same points, then

$$d : d' :: r : r', \text{ whence } r' = \frac{d'r}{d}.$$

"The potential of a point" is the difference between the potential of that point and that of the earth reckoned as a zero.

III. Ohm's Law. *The strength of a current is directly proportional to E.M.F., and inversely proportional to resistance.* This relation is generally expressed

$$C = \frac{E}{R}, \text{ or } C = \frac{E}{r + R},$$

when it is important to separate the internal from the external resistance. It will be seen that the foregoing law is only an application to a specific case of a universal fact; viz., that an effect is directly proportional to that which tends to produce it, and inversely proportional to that which tends to oppose it.

IV. *Resistance varies* (1) *as the length of conductors; it varies* (2) *inversely as the areas of cross sections of conductors or the squares of diameters of cylindrical conductors; it varies* (3) *inversely as the specific resistances of the substances used for conductors.*

V. *E.M.F. depends upon the nature and condition of the substances which compose the battery, and is independent of the size of the plates and their distances apart.*

VI. *Where there are no leakages the strength of a current is equal at all points in a circuit.*

GROUPING OF CELLS.

VII. *For a given battery of cells the most effective way of grouping them, when they are required to work through a given external resistance, is that in which the difference between the external and internal resistance is least. Hence a given battery works to the greatest advantage when the external and internal resistances are equal.*

It must not be inferred from the latter statement that when the internal resistance is less than the external resistance, that we should increase the internal resistance for the sake of the resistance. The internal resistance of itself is a positive disadvantage. The necessity for so great an internal resistance results only from the fact that it is an unavoidable accompaniment of high E.M.F. when that is obtained by connecting in series the requisite number of cells.

To get the maximum current through a high resistance it is clear that we will gain more by the increase of E.M.F. resulting from connecting cells in series, than we will lose by the accompanying increase of resistance, since the latter is but a small part of the whole. If the external resistance is very small so that the resistance of the cells is a large part of the whole, we shall gain very little by arranging them in series, since we should increase the total resistance of the circuit in nearly the same ratio as we should the E.M.F. If we arrange them abreast, we shall neither gain nor lose in E.M.F., but we shall reduce rapidly the total resistance of the circuit.

VIII. *The current will be a maximum when the number of cells connected abreast is numerically equal to* $\sqrt{nr \div R}$.

Thus, suppose the number of cells is 40, and $r = 3$ ohms, and $R = 8$ ohms, then $\sqrt{40 \times 3 \div 8} = 3+$, nearly 4; hence, four cells should be connected abreast, and the ten groups connected tandem.

The following law as given by Gordon will be found very convenient.

To obtain a maximum current, the ratio of the number of cells in series to the number of cells connected abreast should equal the ratio of the external resistance to the resistance of a single cell. That is, C is a maximum when $\frac{N}{n} = \frac{R}{r}$, or when $R = \frac{N}{n} r$, in which N is the number of cells in series and n the number connected abreast.

LAW OF DIVIDED CIRCUITS.

IX. *When a circuit is so constituted that at some point there are two paths open to the circuit, the current will divide between these two paths in the inverse ratio of their resistances, and the joint resistance of the two paths will be neither the sum nor the difference of their respective resistances, but will be expressed by the product of these resistances divided by their sum.*

ESTIMATING WORK DONE BY A CURRENT.

X. *The mechanical work of a current may be calculated from the following formula, in which* C *is the current strength, and* V *is the difference in potential of the terminals of the instrument in which the work is done:*—

$$\frac{\text{C ampères} \times \text{V volts}}{745} = \textit{rate of doing work in horse-powers.}$$

For example, to find the rate at which actual work is consumed in an electric lamp, measure the whole current in ampères; measure the difference of potential (with an electrometer) between the terminals of the lamp in volts; multiply them together, and divide by 745; the result will be the number of horse-powers used up in the lamp. That is, a current of C ampères falling V volts will perform, in passing through the instrument, work at the rate of $x\left(=\frac{C \text{ ampères} \times V \text{ volts}}{745}\right)$ horse-powers.

XI. *The amount of chemical decomposition produced by a current in a given time varies as the strength of the current.* On this principle is constructed the voltameter, which measures the strength of the current by the amount of chemical action it effects.

XII. *The weight in grams of an element deposited by electrolysis is found by multiplying its electro-chemical equivalent* (*i.e.*, the atomic weight divided by the valency) *by the strength of the current in ampères, and this product by the time in seconds during which the current electrolyzes.*

A current of one ampère strength will decompose about three grams of water per hour. A current of n ampères will decompose 0.0000973 n grams of water per second.

XIII. *The number of units of heat developed in a conductor is proportional*, (1) *to its resistance;* (2) *to the square of the strength of the current;* and (3) *to the time the current acts.*

A current of one ampère flowing through a resistance of one ohm, develops therein 0.00024 calorie of heat per second. Hence,

$$H \text{ (calories)} = C^2 \text{ (ampères)} \times R \text{ (ohms)} \times t \text{ (seconds)} \times 0.00024.$$

That portion of a current not expended in external work is "frittered down into heat," either in the battery or in some part of the circuit, or in both.

The absolute amount of heat generated by the oxidation of a given quantity of zinc is perfectly constant; but it may be distributed in various proportions between the battery and the external circuit.

Whenever the current heats a wire, produces decomposition, or performs work of any kind, each of these acts is accomplished at the expense of the heat in the battery. If the current turn an electro-magnetic engine which pumps water, or lifts a hammer, the battery loses heat by these mechanical acts. The precise amount of heat thus lost is restored by the falling of the water, or of the hammer. So also when water is decomposed in a voltameter, the battery loses an amount of heat equal to that which would be produced by the recombination of the separated oxygen and hydrogen.

Faurè corroborates these results in a series of careful experiments, in which he interposed increased resistance by increasing the length of the wire connecting the two ends of the battery. His main results are given in the following table:—

Length of Wire.	Internal Heat of Battery. (Units.)	Heat outside the Battery. (Units.)	Total. (Units.)
25	13127	4965	18092
50	11690	6557	18247
100	10439	7746	18185
200	8992	9030	18022

LAWS OF THE ELECTRO-MAGNET.

I. *In order to produce the most advantageous effect, the resistance of the helix of an electro-magnet should be equal to that of the portion of the circuit not included in the helix, i.e.*, to the rest of the circuit. *When several electro-magnets are used in the same circuit, the sum of the resistances of all the helices should be equal to the resistance of the rest of the circuit.*

Caution. Having decided correctly the resistance an electro-magnet should have, it is possible to make a serious error in selecting wire either too fine or too coarse. For example, suppose that an electro-magnet of 4 ohms resistance is to be made. If No. 20 wire is used, it will require about 170 yds.; but if No. 32 wire is used, it will require only 16 yds. The latter would give only a few convolutions, which might not produce the maximum magnetic effect; while the former might be so coarse that the outside layers would have little effect on the core; hence the maximum effect in neither case would be obtained. In electro-magnets of ordinary size the best distance for the outside layer from the core is between three-eighths and half an inch. Or, in general,

II. *The thickness of the helix should be equal to the diameter of the core.*

It is apparent from the above laws that we would choose for a short circuit, or for a circuit where there is little other resistance, an electro-magnet of small resistance, *i.e.*, one made of coarse wire. On the other hand, for a long circuit, or a circuit of high resistance, an electro-magnet of high resistance, *i.e.*, one made of fine wire, should be ordered. Not because high resistance of itself is advantageous (it is a positive disadvantage), but in order to make the most of the existing current, weakened by the other high resistance in the circuit, we require many turns of wire, the resistance which it brings with it being a necessary but an unwelcome adjunct. "The condensed reason why we use fine wire — and a great deal of it — for circuits of high resistance, is that the high resistance of the circuit greatly enfeebles the current, and we must use fine wire to make the best of the remaining strength of the current by a greatly-increased number of convolutions."

Why is not a magnet containing many convolutions of fine wire — in other words, a high resistance magnet — as efficacious in producing magnetic effects when in a circuit of low resistance as when in a circuit of high resistance? It would be equally efficacious if, by introducing the high resistance magnet, the whole resistance of the circuit in both cases were proportionately increased, and thereby the current proportionately decreased. Take an example. Suppose the whole resistance of a circuit including that of the battery is 20 ohms. Then a magnet suited to this circuit should have a resistance of 20 ohms. The introduction of this magnet will double the resistance of the circuit and reduce the current strength one-half. But if the entire resistance of the circuit is 1 ohm, and a magnet of 20 ohms' resistance is introduced, the entire resistance of the circuit will become 21 ohms, and the current is reduced to one twenty-first its former strength. In the latter case, the advantage derived from the great number of convolutions of wire in the magnet cannot compensate for the great reduction of current.

Roughly, "the total length of the core, including both arms and the back armature or connecting yoke, should be about eleven times the diameter. When, however, the circuit is long and the electric source is of feeble energy, the magnet should be long and of small diameter. When, on the contrary, the circuit is short and the current strong, the core should be of large diameter."

"The attraction of magnets for prismatic armatures at a distance is greatest when they are presented flatwise: but when in contact, the attractive force is greatest when they are presented edgewise." — Fiske.

Electro-magnets with short cores charge and discharge more rapidly than those with long ones. Advantage is taken of this in constructing telegraph sounders and relays.

III. *The attractive force exerted by an electro-magnet is proportional to the diameter of the core and to the square root of its length.*

IV. *The attractive force of electro-magnets is proportional to the square of the strength of current for a like number of convolutions, and to the square of the number of convolutions for like strength of current.*

If the strength of the current (acting on the electro-magnet) and the number of convolutions in the helix vary at the same time, which is nearly always the case, since by increasing the number of convolutions without changing the battery we increase the resistance of the circuit, and thereby weaken the current,

V. *The attractive force of the electro-magnet is proportional to the square of the strength of the current multiplied by the square of the number of convolutions.*

VI. *The maximum of saturation depends solely upon the mass of iron contained in the electro-magnet irrespective of its form.*

VII. *The maximum degree of magnetization, of which a mass of soft iron is susceptible under the influence of the electric current, is more than five times as great as that which a corresponding mass of hardened steel is capable of retaining.*

ELECTRICAL UNITS ADOPTED IN PRACTICE.

Resistance. The resistance offered by 37.8^{m} (41.3 yds.) of pure copper wire, size No. 20 (New British standard Wire Gauge), diameter, 0.914^{mm} (0.36 in.), temperature 15° C., is 1 *ohm.* The *megohm* is 1,000,000 ohms.

The legal ohm is the resistance of a column of mercury 106^{cm} *long and* 1^{qmm} *in section at* 0° *E.*

Potential, electro-motive force. The difference of potential between the plates of a Daniell or Gravity cell, or the electro-motive force of one of these cells, is about 1 *volt.* The volt is the difference of potential or electro-motive force necessary to sustain a current of 1 ampère strength against a resistance of 1 ohm.

Current strength. A current flowing in a wire of resistance 1 ohm, between the two ends of which a difference of potential of 1 volt is maintained, is the unit of current, or current strength, and is called an *ampère.* It is a current of 1 coulomb per second.

Quantity of electricity. The amount of electricity conveyed in 1 second by a current of 1 ampère is called 1 *coulomb.* It is the quantity that would charge a condenser of 1 farad capacity, under an E.M.F. of 1 volt.

Electrostatic capacity. The capacity of a condenser, which would contain 1 coulomb of electricity when charged by an electro-motive force of 1 volt, is 1 farad. A *microfarad* is a millionth part of a farad.

Rate of doing work. The rate at which work must be done in maintaining a given current against a given resistance is measured by EC, in which E is reckoned in volts and C in ampères. Hence, rate of doing work, the power of a current, or the rate at which work is given out in a circuit, is measured by its EC. The unit employed is called a *watt*, or *volt-ampère*, and is the power developed by 1 ampère falling 1 volt.

Work done. The work done in 1 second, when the rate of working is 1 watt, or the work obtained by letting down 1 coulomb of electricity through a difference of potentials of 1 volt is 1 *joule*, or *volt-coulomb*.

EQUIVALENTS OF WORK.

$$1 \text{ joule or volt-coulomb} = \begin{cases} 0.101937^{\text{kgm}}. \\ 0.737324 \text{ ft. lb.} \\ 0.00024067 \text{ calorie of heat.} \\ 10^7 \text{ ergs.} \end{cases}$$

$1^{\text{kgm}} = 9.81$ joules; 1 ft. lb. $= 1.35626$ joules.

EQUIVALENTS OF POWER.

$$1 \text{ watt or volt-ampère} = \begin{cases} 0.00134059 \text{ horse-power.} \\ 0.101937^{\text{kgm}} \text{ per second.} \\ 6.11622^{\text{kgm}} \text{ per minute.} \\ 0.000240670 \text{ calorie per second.} \\ 0.144402 \text{ calorie per minute.} \\ 10^7 \text{ ergs per second.} \end{cases}$$

1 horse-power $= 745.941$ watts; 1 ft. lb. per second $= 1.35626$ watts; 1^{kgm} per second $= 9.81$ watts.

SOURCES OF ENERGY.

Primary Sources.

1. Primordial energy of chemical affinity.
2. Solar radiation.
3. Energy of the earth's rotation.
4. Internal heat of the earth.

Secondary Sources.

- A. *Potential.*
  - 1. Combustibles.
  - 2. Food of animals.
  - 3. Ordinary water-power.
  - 4. Tidal water-power.
- B. *Kinetic.*
  - 5. Winds and ocean currents.
  - 6. Hot springs and volcanoes.

CLASSIFICATION OF VARIOUS FORMS OF ENERGY.

- I. MECHANICAL ENERGY.
  - A. *Visible kinetic energy; i.e.,* energy of a body in visible motion.
  - B. *Potential energy of visible arrangement; e.g.,* a stone elevated above the earth.
- II. MOLECULAR ENERGY.
  - C. *Kinetic energy of electricity in motion.*
  - D. *Kinetic energy of radiant heat and light.*
  - E. *Kinetic energy of absorbed heat.*
  - F. *Molecular potential energy; e.g.,* the so-called "latent heat."
  - G. *Potential energy of electrical separation.*
  - H. *Potential energy of chemical separation; e.g.,* oxygen and hydrogen.

A + B + C + D, etc., = a constant quantity.

TABLES OF REFERENCE.

SPECIFIC GRAVITY OF VARIOUS SUBSTANCES.

	Specific gravity.		Specific gravity.
Acetic acid	1.060	Deal, Norway	0.689
Alcohol	0.792	Diamond	3.530
Aluminium, sheet	2.670	Earth from	1.520
Antimony, cast	6.720	to	2.000
Ash, dry	0.690	Ebony	1.187
Ash, green	0.760	Elm	0.579
Asphalt	2.500	Elm, Canadian	0.725
Basalt	2.950	Ether	0.716
Beech, dry	0.690	Feldspar	2.600
Bell-metal	8.050	Fir, spruce	0.512
Birch	0.690	Firestone	1.800
Bismuth, cast.	9.822	Glass, flint	3.000
Bisulphide of carbon	1.293	Glass, crown	2.520
Boxwood	1.280	Glass, common green	2.520
Brass, cast	8.400	Glass, plate	2.760
Brass, sheet	8.440	Gold	19.360
Brick, common from	1.600	Gold, 20 carats	15.700
to	2.000	Granite	2.650
Carbon, gas	1.760	Gun-metal (10 cop., 1 tin)	8.561
Carbonic acid, liquid	0.830	Gutta-percha	0.966
Cedar, American	0.554	Gypsum	2.286
Cedar, Lebanon	0.486	Human body	0.890
Cedar, West Indian	0.748	Hydrochloric acid	1.200
Cedar, Indian	1.315	Ice at 32°	0.930
Chalk	2.330	Iron, cast, average	7.230
Chestnut	0.606	Iron, wrought, average	7.780
Clay	1.900	India-rubber	0.930
Coal, anthracite	1.600	Iodine	4.950
Coal, bituminous	1.270	Ivory	1.820
Cobalt	8.800	Lead, cast	11.360
Concrete, ordinary	1.900	Lead, sheet	11.400
Concrete, in cement	2.200	Lignum vitæ	1.333
Cork	0.240	Lime, quick	0.843
Copper, cast	8.607	Limestone	3.180
Copper, sheet	8.780	Logwood	0.913

SPECIFIC GRAVITY OF VARIOUS SUBSTANCES.— *Continued.*

	Specific gravity.		Specific gravity.
Magnesium	1.750	Platinum, average	21.531
Mahogany, Honduras	0.560	Plumbago	2.267
Mahogany, Nassau	0.668	Quartz	2.650
Mahogany, Spanish	0.852	Rock salt	2.257
Maple	0.675	Saltpeter	1.900
Marble	2.720	Sand, quartz	2.750
Mercury	13.596	Sand, river	1.880
Milk	1.032	Sand, fine	1.520
Mortar, average	1.700	Sand, coarse	1.610
Muriatic acid	1.200	Silver	10.474
Naphtha	8.470	Slate	2.880
Nitric acid	1.217	Sulphur, natural	2.033
Oak, American, red	0.850	Sulphuric acid	1.840
Oak, American, white, dry	0.779	Tallow	0.940
Oak, live, seasoned	1.068	Tar	1.010
Oak, live, green	1.260	Teakwood	0.806
Oil, linseed	0.940	Tile, average	1.830
Oil, olive	0.915	Tin, cast	7.290
Oil, turpentine	0.870	Water, 32°	0.999
Oil, whale	0.923	Water, 212°	0.958
Phosphorus	1.830	Water, distilled, 39°	1.000
Pine, red, dry	0.590	Water, sea	1.627
Pine, white, dry	0.554	White metal (Babbitt)	7.310
Pine, yellow, dry	0.461	Willow	0.400
Pine, pitch	0.660	Zinc, cast	7.000
Pitch	1.150		

GASES.

	Specific gravity.		Specific gravity.
Air, 32°	1.0000	Hydrogen	0.6930
Ammonia	0.5367	Marsh gas	0.5596
Carbonic acid	1.5290	Nitrogen	0.9714
Carbonic oxide	0.9670	Oxygen	1.1057
Coal gas	from 0.3400 to 0.6500	Sulphuretted hydrogen	1.1912
		Sulphurous acid	2.2474
Chlorine	2.4600	Vapor of water	0.6235
Hydrochloric acid	1.2540		

AVERAGE COMPOSITION OF ALLOYS.

	Standard English gold coins.	Standard English silver coins.	Brass.	Dutch metal.	Gun metal.	Speculum metal.	Medal bronze.	German silver.	Solder, ordinary.	Pewter.	Type metal.	Fusible metal.	Shot.
Gold	92	..	..	..	..	..	..	..	..	..	..	..	..
Silver	8	93	..	..	..	..	..	..	..	..	..	..	..
Copper		7	69	75	85	60	93	55	..	..	..	..	..
Tin	..	..	..	3	15	30	7	..	50	80	3	25	..
Zinc	..	..	31	19	..	..	..	27	..	..	..	..	..
Lead	..	..	..	3	..	..	..	..	50	20	80	25	98
Antimony	..	..	..	..	..	..	..	..	..	..	17	..	..
Arsenic	..	..	..	..	..	10	..	..	..	..	..	..	2
Bismuth	..	..	..	..	..	..	..	..	..	..	..	50	..
Nickel	..	..	..	..	..	..	..	18	..	..	..	..	..

FRIGORIFIC MIXTURES FOR THE ARTIFICIAL PRODUCTION OF COLD.

NOTE. To obtain the following results, the temperature of the ingredients must be reduced previously to the given temperature by some of the other mixtures. The last four mixtures yield the temperatures given whatever may be the previous temperature of the ingredients. The temperatures given are of the Fahrenheit scale.

	Proportional parts, by weight, in the mixture.											
Water	..	..	..	..	..	..	..	..	..	..	..	..
Sal ammoniac	16	1	..	..	..	..	..	..	..	1	5	..
Nitre	5	..	..	..	..	..	..	..	..	..	5	..
Common salt	5	..	..	..	1	..	..	..	1	2	10	5
Nitrate of ammonia	..	1	5	6	..	..	..	..	..	..	..	5
Sulphate of soda	..	..	6	..	..	..	..	..	..	..	..	..
Carbonate of soda	8	1	..	..	..	..	..	..	..	..	..	..
Phosphate of soda	..	..	..	9	..	..	..	..	..	..	..	..
Potash	..	..	..	..	..	..	..	4	..	..	..	..
Muriate of lime	..	..	..	..	..	..	5	..	..	..	..	..
Snow or pounded ice	..	..	..	..	1	8	4	3	2	5	24	12
Diluted nitric acid	..	..	4	4	..	..	..	..	..	..	..	..
" sulphuric acid	..	..	..	..	..	10	..	..	..	..	..	..
Temp. of ingredients	+50	+50	+50	+50	+32	−68	+32	+32	..	..	..	..
" of the mixture	+4	−7	−14	−21	0	−91	−40	−51	−5	−12	−18	−25
Cold produced	46°	57	64	71	32	23	72	83	..	..	..	..

TABLE OF LINEAR DILATATIONS OF SOLIDS.—STEWART.

Name of Substance.	Length at 100° C. of a rod whose length at 0° C. = 1.000000.	Name of Observer.
Glass (tube)	1.000776	Roy and Ramsden.
Copper	1.001722	Lavoisier and Laplace.
Brass	1.001867	" "
Iron, soft (forged)	1.001220	" "
Steel (untempered)	1.001079	" "
" (tempered yellow)	1.001240	" "
Cast iron	1.001072	Daniell.
Lead	1.002848	Lavoisier and Laplace.
Tin	1.001767	Daniell.
Silver	1.001951	"
Gold (standard of Paris, not annealed)	1.001552	Lavoisier and Laplace.
Platinum	1.000884	Dulong and Petit.
Zinc	1.002976	Daniell.

RELATIVE THERMAL CONDUCTIVITY OF METALS.

Silver	100.0	Steel	11.6
Copper	73.6	Lead	8.5
Gold	53.2	Platinum	8.4
Brass	23.6	Palladium	6.3
Tin	14.5	Bismuth	1.8
Iron	11.9		

SPECIFIC HEATS.

Lead	0.0314	Tin	0.0562
Iron	0.1140	Ether at 17°	0.5160
Glass	0.1900	Alcohol at 17°	0.6150
Gold	0.0324	Quicksilver	0.0333
Copper	0.0951	Oil of turpentine at 17°	0.4260
Brass	0.0940	Water at 0°	1.0000
Platinum	0.0324	Water mean between 0° and 100°	1.0050
Silver	0.0570		
Zinc	0.0955		

CROSS-SECTION OF ROUND WIRES, WITH RESISTANCE AND WEIGHT OF PURE COPPER WIRES, ACCORDING TO THE BIRMINGHAM WIRE GAUGE. —GRAY.

Temperature 15° C.

B.W.G.	Diameter.		Area of Cross-section.		Resistance.		Weight (density = 8.95).	
No.	Ins.	Cms.	Sq. Ins.	Sq. Cms.	Ohms per Yard.	Ohms per Meter.	Lbs. per Yard.	Grms. per Meter.
0000	.454	1.1530	.1620000	1.0444000	.000152	.000167	1.884000	934.7000
000	.425	1.0790	.1420000	.9150000	.000174	.000190	1.651000	819.1000
00	.380	.9650	.1130000	.7320000	.000217	.000238	1.320000	654.8000
0	.340	.8640	.0908000	.5860000	.000272	.000297	1.056000	524.2000
1	.300	.7620	.0707000	.4560000	.000349	.000382	.822000	408.1000
2	.284	.7210	.0633000	.4090000	.000389	.000425	.737000	365.8000
3	.259	.6580	.0527000	.3400000	.000468	.000512	.613000	304.2000
4	.238	.6050	.0445000	.2870000	.000554	.000606	.518000	256.9000
5	.220	.5590	.0380000	.2450000	.000649	.000709	.442000	219.5000
6	.203	.5160	.0324000	.2090000	.000762	.000833	.377000	186.9000
7	.180	.4570	.0254000	.1640000	.000969	.001060	.296000	146.9000
8	.165	.4190	.0214000	.1380000	.001150	.001260	.249000	123.5000
9	.148	.3760	.0172000	.1110000	.001430	.001570	.200000	99.3000
10	.134	.3400	.0141000	.0910000	.001750	.001910	.164000	81.4000
11	.120	.3050	.0113000	.0730000	.002180	.002380	.132000	65.5000
12	.109	.2770	.0093300	.0602000	.002640	.002890	.109000	53.9000
13	.095	.2410	.0070900	.0457000	.003480	.003800	.082500	40.9000
14	.083	.2110	.0054100	.0349000	.004560	.004980	.063000	31.2000
15	.072	.1830	.0040700	.0263000	.006060	.006620	.047400	23.5000
16	.065	.1650	.0033100	.0214000	.007430	.008130	.038600	19.2000
17	.058	.1470	.0026400	.0170000	.009330	.010200	.030700	15.3000
18	.049	.1240	.0018900	.0122000	.013100	.014300	.022000	10.9000
19	.042	.1070	.0013900	.0089400	.017800	.019600	.016100	8.0000
20	.035	.0889	.0009620	.0062100	.025600	.028000	.011200	5.5600
21	.032	.0813	.0008040	.0051900	.030700	.033500	.009360	4.6400
22	.028	.0711	.0006160	.0039700	.040000	.043800	.007160	3.5500
23	.025	.0635	.0004910	.0031700	.050200	.054900	.005710	2.8300
24	.022	.0559	.0003800	.0024500	.064900	.070900	.004420	2.1900
25	.020	.0508	.0003140	.0020300	.078600	.085800	.003670	1.8200
26	.018	.0457	.0002540	.0016400	.096900	.106000	.002960	1.4700
27	.016	.0406	.0002010	.0013000	.123000	.134000	.002340	1.1600
28	.014	.0356	.0001540	.0009930	.160000	.175000	.001790	.8890
29	.013	.0330	.0001330	.0008560	.186000	.203000	.001540	.7660
30	.012	.0305	.0001130	.0007320	.218000	.238000	.001320	.6530
31	.010	.0254	.0000785	.0005070	.314000	.343000	.000915	.4540
32	.009	.0229	.0000636	.0004100	.388000	.424000	.000746	.3670
33	.008	.0203	.0000503	.0003240	.491000	.536000	.000585	.2900
34	.007	.0178	.0000385	.0002480	.641000	.701000	.000442	.2200
35	.005	.0127	.0000196	.0001270	1.260000	1.370000	.000229	.1130
36	.004	.0102	.0000126	.0000811	1.960000	2.150000	.000146	.0726

THE FOLLOWING TABLE EXHIBITS THE DECLINATION OF THE NEEDLE IN DEGREES FOR A SERIES OF DECADES AT DIFFERENT POINTS ON THE NORTH AMERICAN CONTINENT. THE PLUS (+) SIGN PREFIXED TO A NUMBER INDICATES A WESTERN DECLINATION, AND THE MINUS (—) SIGN AN EASTERN DECLINATION.

Year (Jan. 1)	Halifax, N.S.	Cambridge, Mass.	New York City.	Washington, D.C.	Erie, Pa.	New Orleans, La.	San Francisco, Cal.	Sitka, Alaska.
1700		+ 9.80	8.50					
1710		9.20	8.00					
1720		8.70	7.60			– 3.40		
1730		8.30	7.20			– 3.70		
1740		7.90	6.60			– 4.10		
1750	+ 12.5	7.50	5.90			– 4.70		
1760	13.0	7.20	5.20			– 5.30		
1770	13.7	7.00	4.60			– 5.90		
1780	14.4	6.90	4.40			– 6.50		
1790	15.1	6.90	4.29	– 0.10	– 0.70	– 7.00	– 12.80	
1800	15.9	7.10	4.28	0.00	– 0.70	– 7.50	– 13.40	– 26.12
1810	16.7	7.50	4.30	+ 0.30	– 0.60	– 7.90	– 13.90	– 27.11
1820	17.4	8.00	4.47	0.60	– 0.30	– 8.10	– 14.42	– 27.89
1830	18.1	8.64	4.91	1.00	+ 0.03	– 8.20	– 14.92	– 28.48
1840	18.7	9.33	5.59	1.49	0.44	– 8.14	– 15.38	– 28.88
1850	19.3	10.03	6.34	1.99	0.91	– 7.94	– 15.78	– 29.08
1860	19.8	10.67	6.96	2.47	1.39	– 7.61	– 16.11	– 29.08
1870	20.1	11.51	7.43	2.90	1.87	– 7.15	– 16.36	– 28.88
1880	+ 20.3	+ 11.63	+ 7.84	+ 3.26	+ 2.31	– 6.62	– 16.52	– 28.50

NOTE. "The west declination of the magnetic needle at Cambridge, Mass., for the beginning of 1884 is + 11.766°, and increased annually, at the epoch 1880, 0.0347°. The minimum west declination at this place occurred about the epoch 1782, 0.7°. The magnetic dip at this place is 74°."—E. C. PICKERING, Harvard College Observatory.

MEAN INDICES OF REFRACTION AND DISPERSIONS OF SEVERAL SUBSTANCES.

	Index of Refraction.	Dispersion.
Crown glass (mean)	1.530000	0.0220
Flint glass (mean)	1.600000	0.0420
Water	1.336000	0.0132
Alcohol	1.372000	0.0133
Carbon disulphide	1.680000	0.0837
Canada balsam	1.540000	
Air	1.000294	

PART II.

MANUAL OF MANIPULATION, ETC.

HOW TO TURN ON A SCREW.

When the threads of screws are very fine, as, for example, those of the male and female screws connecting the different parts of microscopes and telescopes, etc., it is often difficult to start them properly, so that they may be turned on without injury to the threads. The female screw should be first applied to the male screw, and *turned back* until the two fit each other, so that one settles naturally into the other without any canting of the male screw.

HOW TO MAKE A GOOD BEND IN GLASS TUBING.

Hold the tubing widthwise the flat flame of an ordinary gas-burner (not a Bunsen flame) or a kerosene flame, and about midway the flame vertically, heat until the glass softens, and always remove the tube from the flame while bending. To prevent flattening at the bend, stop up one end of the tube and blow gently into the other end, while bending.

HOW TO ANNEAL COPPER AND BRASS.

Raise to a red heat the part to be rendered flexible, and thrust it into cold water.

HOW TO MAKE PASTE FOR LABELLING GLASS BOTTLES.

Pulverize a small quantity of starch, place it upon a piece of tin, and the tin on a hot stove; stir the starch that it may not burn, and heat until it becomes yellowish brown. Then boil it in water and make a thick paste. The paste may be kept from souring and preserved for a long time by adding a few drops of creosote.

HOW TO CLEAN GLASS.

If the glass is very greasy, wash it with alkaline soap and warm water, dry it with a linen towel, and rub it well with a crumpled newspaper to give it a fine lustre. It is often sufficient to breathe well upon the glass a few times previous to rubbing with newspaper. Glass lenses should be cleaned with chamois leather only.

Some kinds of organic matter, such as many of the gums, are best removed with alcohol. Strong sulphuric acid applied for a considerable time will usually so char organic matter that the residue can be easily removed subsequently with water.

Glass tubes which have become dirty with the oxide of mercury are easily cleaned with dilute nitric acid.

Clean the bores of glass capillary tubes with a solution of potassium hydrate.

USEFUL CEMENT.

Cut gutta-percha into fine shreds, melt it with an equal quantity of pine pitch, stirring for some time.

CARE OF AIR-PUMPS.

Air-pumps with brass plates are objectionable on account of the softness of the metal rendering them liable to be scratched and indented. Iron or ground-glass plates are preferable. The oil which is used upon the plates will sufficiently protect iron plates from rust.

About a half-teaspoonful of sperm oil should be poured into the hole in the plate occasionally. The oil will be drawn up to the parts needing it as the pump is worked. About the same quantity of oil should occasionally be poured into the little cup on top of the barrel through which the piston-rod plays.

Care should be taken that no dust adheres to the edges of the glass receivers, as much of the dust is of a hard nature, and would scratch the plate of the pump. Hence, when the receivers are temporarily removed from the pump-plate, they should be set on clean paper. In using the pump, place the receiver on the plate, and with an oiler deposit a little oil on the plate close to the edge of the receiver. Tallow is an excellent substitute for oil to be used on the plate. Give the receiver a few turns upon the plate, and repeat the same after having made two or three strokes of the air-pump.

A good way to test a pump is to place the apparatus shown in Fig. 36, Physics, under the receiver of an air-pump, and by exhaustion cause the bubble of air in the bulb to force out all the water in the bulb and stem, continuing the process for some time after. Then allow the apparatus to remain in this condition for a half an hour or more, and see to what extent the water will be forced back into the stem and bulb in consequence of leakage.

When the exhaustion is nearly complete, the pump-handle will work freely, and a slight hissing sound will be heard at the end of the stroke, due to the expulsion of the remaining air. For this reason the piston must be moved until it strikes the end of the cylinder each time (*i.e.*, the lever must be elevated and depressed as far as possible), and the strokes must be taken steadily and not too fast.

A convenient barometer gauge may be constructed as follows. Take a piece of glass barometer tubing, about 15 in. long, closed at one end, bend it into a U-shape, so that the arm with the closed end shall be about 6 in. long. Fill the closed arm and about one inch of the open arm with mercury. Place it in some convenient glass vessel for a support, and place the whole under the receiver of an air-pump. Exhaust the air until the mercury in both arms stands at nearly the same level. In a good pump there ought not to be a difference of level exceeding 2^{mm} to 4^{mm}.

MAGDEBURG HEMISPHERES.

Not a few teachers (we judge from observation) are in the habit of teaching their pupils to calculate the force necessary to separate the Magdeburg hemispheres, by multiplying 15 lbs., the average atmospheric pressure per square inch, by the area of the external surface of the sphere. This is an egregious error. The force should be calculated by multiplying 15 lbs. by the area in square inches of a cross-section of the sphere. The error is two-fold. First, the force required would be no less, if, instead of hemispheres, shallow, flat cups of the same diameter at the plane of contact, and having a depth not exceeding a thousandth of an inch, were used, although it will be seen that the external area is much less than that of a sphere of the same diameter.

For example, the diameter of the piston of the Seven-in-one apparatus is 5¾ inches. Its external area is therefore 33.06 sq. in., and the force necessary to pull the piston out in case the apparatus is perfectly tight, and there is a perfect vacuum between the piston and the end of the cylinder, is 15 × 33.06 = 389.5 lbs. Precisely the same force would be required to separate a pair of Magdeburg hemispheres having the same diameter. Let the teacher who is incredulous respecting the above statement draw a circle upon paper. At different points about the circle erect perpendiculars to the same. Draw a diameter of the circle. Now let him imagine that the circle represents a section of a sphere, and that it is divided by the diameter into two hemispheres. Of course the pressure of the atmosphere at every point on the sphere is normal to that point, and the several perpendiculars erected represent the direction of the pressure at those several points. Now the pressure at every point on the sphere (with the exception of the two opposite points, where the pressure is normal to the plane of contact) is resolvable into two components, one of which is normal to the plane of contact, and the other parallel with it. The latter is wholly ineffectual in holding the hemispheres together, in other words, causes no pressure between them. The first component, of course, decreases (and the latter increases) towards the plane of contact where it becomes zero. Now it may be demonstrated that the sum of all the components normal to the plane of contact is equal to the pressure upon a flat disk, whose area is equal to the area of the plane of contact.

The second error consists in supposing that the external area of the entire sphere is to be used as a factor of the force necessary to separate them. Or, as we should now say, that the sum of the areas of the opposite surfaces of a flat disk is to be used as a factor. One may be convinced of this error by imagining that the handle of one of the hemispheres is attached rigidly to a wall, and that he pulls on the handle of the other hemisphere with a force sufficient to separate them. He certainly would not consider that the pressure of the atmosphere against the hemisphere attached to the wall would tend to prevent a separation. Yet the force necessary to separate them in this case is not different from that which would be required if, by grasping both handles with his hands, he should separate them. The error is precisely analogous to that which would be made by a person who, if he should connect two spring-balances with each other, and, while pulling them apart, each should register 20 lbs., should imagine that he was exerting a force of 40 lbs.

THE POUND, GRAM, ETC., AS UNITS OF MASS AND UNITS OF FORCE.

It is highly important that the pupil should early learn to distinguish between the terms gram, kilogram, pound, etc., used as units of mass, and the same terms used as units of weight or force as employed in the gravitation system; that the unit of mass is unchangeable and has a definite value, while the units of force expressed in grams, kilograms, pounds, etc., vary with locality, and consequently have no value as terms of comparison except in localities similarly situated.

For example, in the Absolute System, a cubic centimeter of water at 4° C. is taken as a standard of the unit of mass. It is called a *gram-mass*. It is not subject to variations, and therefore has a fixed and definite value. In the gravitation system the weight of this mass, or the force of gravity acting on it, is also called a gram. Now, force is measured by the acceleration it produces in a unit of mass ($F = ma$). At sea-level in the Northern States, the acceleration produced by gravity is 980^{cm}, and the force measured in gravitation units is one gram. Imagine this same mass to be transported to a place so far from the earth that the force of gravity produces an acceleration of 1^{cm} per second. The force now acting on it is only $\frac{1}{980}$ as great as before. If a person at this place were to graduate a spring-balance in accordance with the force which a gram-mass of water would exert on it, the gram on this would have only $\frac{1}{980}$ the value of a gram on a spring-balance graduated at the former place.

The value of the gram, then, employed as a unit of force, varies with locality, and can be employed as a unit of comparison only at places similarly situated. Evidently there is great need of a *universal unit* of force.

Now, if we agree to call the force acting on our gram-mass at the latter place, or, generally, if we agree to call any force which will produce in a gram-mass an acceleration of 1^{cm} per second a *dyne*, then the force acting on the same mass at the former place is 980 dynes, and generally we shall have a unit by which we can compare any two forces.

It will be seen that in the Absolute System the units of both force and mass are constant. In this system the unit of force is equal to $\frac{1}{g}$ part of the *weight* of the unit of mass.

The British unit of force (that force which, acting on a pound-mass for one second, produces an acceleration of one foot per second) is the *poundal.* It follows that the weight of a gram-mass at Greenwich and in the Northern United States (since it produces in the mass an acceleration of 980^{cm} per second) is equal to 980 dynes; and the weight of one pound-mass is about 32.2 poundals.

Returning to our illustrations, it will be seen that the force of gravity acting on the gram-mass in one case is 980×1, in the other it is 1×1, and generally the force of gravity or weight (w) is g times the units of mass; hence $W = Mg$ (see page 125, Physics), whence

$$M = \frac{W}{g}.$$

Therefore, the mass of any body, at any place, is found by dividing its weight at that place by the acceleration at the same place.

It must be apparent that the *fundamental units of measurements* are *mass*, *time*, and *space;* all other units, such as units of velocity, acceleration, momentum, force, energy, etc., are derived from these three units; hence they are called *derived units.*

MEASUREMENT OF THE FORCE OF GRAVITY.

The following results of measurements of the force of gravity (g) made with great care by Prof. T. C. Mendenhall, at Tokio, Japan, in the year 1880, are interesting and instructive. The latitude of this place is N. 35° 41′. Value of g (at sea-level) $= 9.7984^{m}$. Length of seconds-pendulum $= 994.59^{mm}$. Time of vibration, one second. On the summit of Mt. Fujinoyama, in the vicinity, at an elevation of 12,441 feet above sea-level, the time of vibration of the same pendulum was 1.000336 seconds. The computed value of $g = 9.7886^{m}$. Mean density of the mountain calculated to be 2.12. At the same elevation, if the mountain did not exist, $g = 9.7865^{m}$. Attraction of the mountain $= 0.00021$ the attraction of the earth. Calculated mean density of the earth, 5.67.

For convenience of comparison, the following data are given: At the earth's pole $g = 9.831^{\text{m}}$ (32.2549 ft.). At the equator $g = 9.781^{\text{m}}$ (32.0902 ft.). In lat. 45° $g = 9.806$. Hence, in dynes to the gram, the force of gravity at the level of the sea varies from 978.2 to 983.1 dynes. In poundals it varies from 32.227 at the pole to 32.117 at the equator (Maxwell).

Length of seconds-pendulum at

The equator, 975.175^{mm} (3.2506 ft).
Quito, elevation 9.500 ft., latitude 13′ S., 974.326^{mm}.
Greenwich, 978.495^{mm} (39.1398 in.).

$$g = 9.8115^{\text{m}} \text{ (32.1912 ft.).}$$

The value of g is obtained by the formula

$$g = \frac{\pi^2 l}{t^2},$$

in which l = length of pendulum; t = the time of one vibration in seconds; $\pi = 3.141592$ = the ratio of the diameter of a circle to its circumference. To determine t, the number of vibrations for a given time, say 30 minutes, is observed, and this number, divided by the number of seconds in the time, gives t.

INERTIA.

The definition of Inertia, given on page 90 of the Physics, has been made the subject of criticism (see "Science," Volume III., No. 66, page 559) on the part of a Harvard University professor; although the definition, so far from being *new*, is the same in substance as that given by nearly all reputable modern writers. We give a few: "The principle of inertia is an abstract principle which must be considered as applicable to a single isolated particle. It may be enounced in the following terms:—An isolated material point cannot change its state, whether of rest or motion. That is to say, if it be at rest, it will remain at rest; if it be in motion, it will continue to move in the same direction and with the same velocity." — DESCHANEL.

"Inertia is a purely negative property of matter; it is the incapability of matter to change its own state of motion or rest." — GANOT.

Daniell, in his excellent treatise on The Principles of Physics, after quoting Newton's First Law of Motion, adds, "And this is tersely expressed by saying that '*Matter has Inertia*.'"

"The inertia of *matter means its passiveness;* that is, its *inability* to change its own condition in regard to motion or rest." — WOOD's "Elementary Mechanics."

"The term 'inertia,' in strict language, means simply the inability of matter to change its state except under the action of some force. It is also universally used in a somewhat different though analogous sense as denoting that property of matter in virtue of which a definite force is necessary to produce a given change in the existing state of a mass. This last is simply a mode of expressing the general idea of momentum." — Prof. C. R. CROSS, Mass. Inst. Technology.

It is true that the eminent physicists, Thomson and Tait, in their "Natural Philosophy," have "unfortunately" made use of the following language: —

"Matter has an innate power of resisting external influences, so that every body, so far as it can, remains at rest, or moves uniformly in a straight line. This, the *inertia* of matter, is proportional to the quantity of matter." Commenting on this passage, the peerless Maxwell pertinently asks: "Is it a fact that matter has any power, either innate or acquired, of resisting external influences? Does not every force which acts on a body always produce exactly that change in the motion of the body by which its value, as a force, is reckoned? Is a cup of tea to be accused of having an innate power of resisting the sweetening influences of sugar, because it persistently refuses to turn sweet unless the sugar is actually put into it?"

The same writer, in his invaluable work on "Matter and Motion," expresses a volume of truth in a few words when he says, "*We are acquainted with matter only as that which may have energy communicated to it from other matter.*"

If a body of matter possesses an innate power to resist the action of an external force, then must this resistance have a *quantitative value.* Assume that the external force is made equal to the resistance; then will there be equilibrium, and no motion will be produced, — a result which is contrary to fact, inasmuch as no body free to move ever refused to move when acted on by a force however small. So the question very pertinently arises, if "matter has an innate power of resisting external influences," *why does it never resist?* The science of modern dynamics will be overturned when an instance occurs. It is doubtless true that every body, "*so far as it can*, remains at rest," etc.; but the fact is that, if a body is free to move, it cannot of itself remain at rest, but every force will cause a "change of motion proportional to the impressed force."

That which Thomson and Tait have called "inertia" is now universally known as *mass.* If inertia is an entity, "an innate power of resisting external influences," then it must be susceptible of a quantitative definition. Let any one attempt to give it a quantitative definition, and he will find himself (as our critic unconsciously did), defining *mass*, which is the only quantitative notion which can be assigned to it. This is made quite clear in the following discussion by the eminent physicist, Dr. C. S. Hastings. Assuming that what Thomson and Tait *meant*, but did not clearly express, was, "that the inertia of a *body* is proportional to the quantity of matter in the body," he says: "Let us consider this amended form, and write I and M for inertia and quantity of matter (or mass) respectively; then the assertion is, that

$$I = MX,$$

where X is a function of anything or everything except mass. Now experience shows us that I, however defined, does not depend upon time, position, temperature, electrification, or, in short, upon any change in physical condition. We must conclude then,

that $X = C$, a constant,

and $I = CM.$

The numerical value of the constant will, in any case, depend upon the system of units selected for measuring I and M; therefore we may so select the system that C becomes equal to unity, whence

$$I = M.$$

It will appear from the above that the term *inertia* has been used in two senses, one qualitative, and the other quantitative. "In the qualitative sense, it simply implies the truth of Newton's First Law of Motion; in the quantitative sense, it is *mass*, and nothing else, as appears from the following definition given by Rankine: '*The mass, or inertia*, of a body, is a quantity proportional to the unbalanced force' (does this expression imply that 'matter has an innate power to resist'?) 'which is required in order to produce a given definite change in the motion of a body in a given interval of time.'"

Since then there is no use for the word in the latter sense; by limiting it, as we have done, to its qualitative sense, we avoid ambiguity, and retain a word of great convenience as an abbreviation of the first law of motion.

While it is well for the teacher to be familiar with the arguments *pro* and *con* which have been presented on this question, it is *not* well to allow the pupil's mind to become confused by the useless discussion. Enforce by many and varied illustrations and examples the following formula,

$$V = \frac{FT}{M};$$

i.e., that velocity varies directly as the force and time, and inversely as the mass. Be sure to direct the attention to the relation which time sustains in each example, and that it enters as a factor in every question of velocity; in other words, that "*it requires time to generate or destroy motion.*"

GRAPHICAL REPRESENTATION OF THE LAWS OF FALLING BODIES.

Compare Fig. 15 with the table on page 105 of the Physics. The vertical lines represent units of time; the horizontal lines, units of velocity; the triangular areas, units of space passed over in each unit of time, also average velocity; and the numbers on the right, the total distance passed over. It would be an excellent practice for the pupil to learn to construct this diagram from memory, as by so doing he will be likely to acquire that which will enable him at any time to reproduce rules which may have faded from the memory. Such has been the experience of Rev. J. J. Griffin, of Ottawa College.

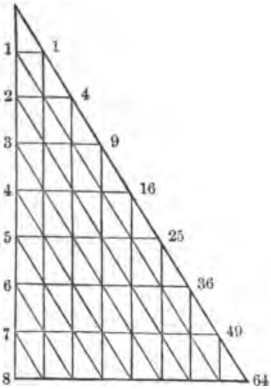
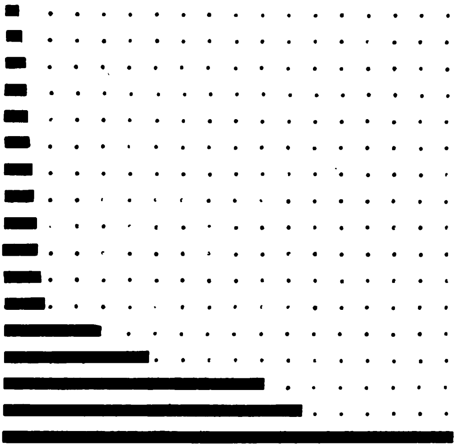


Fig. 15.

SPECIFIC DENSITY.

A graphical representation of the specific densities of the principal metals (similar to the following), prepared on a large scale by the *artist* of the class, framed, and suspended from a wall, will make an appropriate and useful ornament for a laboratory. Instead of solid black bars, as in the following, the bars may be shaded so as to be suggestive of rods. Similar diagrams may be constructed to represent specific electric and heat conductivities, and their reciprocals, *i.e.*, their relative resisting powers.

RODS OF METALS OF EQUAL MASSES AND DIAMETERS.



	Relative densities.	Relative volumes.
Platinum	21.53	0.46
Gold	19.36	0.52
Mercury	13.59	0.75
Palladium	11.80	0.84
Lead	11.36	0.88
Silver	10.47	0.95
Bismuth	9.82	1.02
Copper	8.60	1.16
Iron	7.78	1.28
Tin	7.29	1.37
Zinc	7.00	1.43
Antimony	6.72	1.49
Aluminium	2.67	3.70
Magnesium	1.75	5.71
Sodium	0.98	10.20
Potassium	0.86	11.62
Lithium	0.57	17.54

PROOF OF THE NON-EXISTENCE OF CENTRIFUGAL FORCE.

If a body is perfectly free to move it will move, in the direction of the force acting upon it; so that, if the cord which confines a mass to a circular motion be suddenly severed, the body will move, or, at least, have a component of motion, in the direction which the cord occupied at the instant of severance, *if there is any centrifugal force acting.* Now experience shows that in such a case the body will move exactly at right angles to the direction of the cord; therefore there was no such force acting.

Or it may be regarded in this way. If a free body is acted upon by a force at right angles to its path, it will be deflected in the direction of the force. If the force is constant, and constantly at right angles to the path, the path will be a circle, and the force will be directed towards its centre. It is called *the centripetal force.* Now, if this force is supplied through a string, it will produce a tension of the string, and, as you may regard a tension as being either towards one or the other end of the string, you may regard the force either as centripetal or centrifugal, according to the end from which you look, *though to the moving body it is centripetal;* to the central body only is it centrifugal. This is really the whole cause of the confusion which arises on the subject, the notion that a tension of the string implies a force acting on the body directed away from the center; such a force acts on the *center* only.

Or we may look at it in this way: The tangential velocity at any instant may be resolved into two components, one along the circle, the other away from it, *i.e.*, away from the center; *the latter is nullified by the tension of the string.* The tension of the string then balances the centrifugal component of the tangential velocity at every instant. If the string is cut, the body does not fly straight from the center; hence there is no "centrifugal *force*" counteracted by the tension of the string.

FORMULA FOR CENTRIPETAL FORCE.

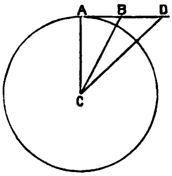


Fig. 16.

The motion of a body moving in a circular path is compounded of a tangential motion and a motion towards the center. If at point A, Fig. 16, its tangential velocity in a unit of time be represented by the line AB, but at the end of the unit of time the body is found at E, it is evident that its acceleration toward the center must have produced in unit of time the change of position represented by BE. Now, it may be proved by geometrical and other methods, that the acceleration $a=\frac{v^2}{r}$, in which v represents the velocity of the body in the direction AB, and r the radius of the circle. If r is constant, the acceleration varies as v^2, and the force which produces the acceleration, *i.e.*, the centripetal force, must vary as v^2. For example, if the tangential velocity at one time is represented by AB or v, and at another time by AD (twice AB) or v_1, then, according to the above, $BE:DF::v^2:v_1^2$. Let F and F_1 represent the forces which produce these accelerations respectively; then $BE:DF::F:F'$; hence $F:F_1::v^2:v_1^2$. Of course this is strictly true only when the arcs are small, but this determines the rate of change which is the measure of the force.

It will now be evident that the centripetal force in all cases may be obtained by the formula $F=\frac{Mv^2}{r}$.

It should be observed here that the effect of the centripetal force, in case the body moves in a circle, is, not to change its momentum, but simply to change its *direction*. Or, as Maxwell expresses it: "If the force acts on a body at right angles to the direction of its motion, it does not work on the body, it alters the direction but not the magnitude of the velocity. The kinetic energy, therefore, which depends on the square of the velocity remains unchanged."

In this connection we would invite attention to a fact not always recognized. Force is defined as that which can produce or change motion; change of motion means change of velocity, but *this includes change of direction;* for, to change the direction of motion of a body, a velocity must be given to it in a direction inclined to its first direction. For example, suppose a body to be moving northward with a given velocity, then, to cause it to move in a north-easterly direction *with the same velocity*, we must add a velocity whose direction is between north-east and south.

CORPUSCULAR THEORY OF HEAT.

It is well to acquaint the pupil with the theory of heat which prevailed less than a century ago, but which is scarcely referred to in text-books of the present day. The following quotations are made from a work on Natural Philosophy, in four volumes, written by George Adams, Mathematical Instrument Maker to his Majesty the King of England, and dated London, 1799. Perhaps no better examination test can be prepared, especially for determining the pupil's proficiency in the mastery of the modern conceptions of this subject, than to place before him these quotations in whole or in part, and require him to point out the exact differences between the corpuscular and the dynamic theories, criticise the former, and explain satisfactorily all the phenomena referred to in accordance with the latter.

"By the word *fire* is meant that very subtile fluid which is the cause of heat, and by which bodies are expanded, fluids raised into vapor, solid bodies rendered fluid, etc. Modern French writers, for the same purpose, use the terms *igneous fluid*, *matter of heat*, and lately *caloric*. Heat, properly speaking, is that sensation which the presence of fire occasions in an animate body; the state of an inanimate body, when it contains fire, is also distinguished by this word; for, we say, the heat of red-hot iron. We ought always by the word *heat* to understand the effect of fire, or fire acting in a certain manner, rather than the element itself which may exist in substances actually cold to the senses. . . . Fire can drive out other matter from any given space; and certainly that which can expel other bodies, and take the place of them, must itself be body. If the ball of a thermometrical tube be filled with air, spirits, or mercury, fire applied underneath will expel them all in their turns; which it cannot do, but in virtue of its own extension; and if it be extended, it is a bodily substance.

"A fluid subject to like laws with the elastic air, must be as material as the air is. Fire, in common with air, is subject to be confined by an incumbent pressure, and released when that pressure is withdrawn. . . .

"Fire would make water boil much sooner if it were not resisted by the pressure of the atmosphere on its surface. . . .

"Fire evaporates also from an heated liquid more slowly, when counteracted by the pressure of the air. . . .

"Nothing can be more strange than to imagine that motion can impart a property which it has not in itself. What kind of connection is there between the ideas of burning, and motion of any sort? or how can motion account for anything but motion? . . .

"There is fire in the wood, and there is air in the field, though we do not perceive either while at rest. Rubbing two pieces of wood does not create fire, any more than the blowing of the wind creates air. Motion renders both perceptible. . . . It is owing to this evaporation upwards, that iron will heat a body held over it sooner than under it. . . .

"Fire never ceases to be a fluid, unless when in a state of combination with other bodies. Fire, when agitated with that motion which is manifested by heat, always acts as if it wanted more room; and this in such a wonderful manner, as if every particle was a radiant point or center. . . .

"*Heat* and *cold* are not names of things essentially different, but only of different degrees of the same thing; that is, of fire in motion. . . .

"Liquefaction is effected by introducing fire between the particles which separates them from one another. . . ."

Latent heat is spoken of as "fire which has lost its faculty of heating."

FREEZING WATER BY ITS OWN EVAPORATION.

We would add to the directions generally given in text-books for performing this experiment a single important suggestion. Hold the small metallic vessel which is to contain the water to be frozen over the flame of a candle so as to cover the interior with soot. Now place five or six drops of ice-water in the vessel after it is well cooled. The water not adhering to the vessel, but assuming a spheroidal state, will be frozen more easily than if allowed to adhere to the vessel. If possible, avoid the use of sulphuric acid in this experiment. In the best pumps water may be frozen by its own evaporation without employing acids to absorb the vapor. If acid should be accidentally spilled upon the face of the pump, it must be quickly and thoroughly wiped off.

WHAT IS ELECTRICITY?

The reply given to this question by those who know most about it is virtually that given by Faraday near the close of his life. He said, "There was a time when I thought I knew something about the matter; but the longer I live, and the more carefully I study the subject, the more convinced I am of my total ignorance of the nature of electricity."

This is by no means an anomalous case. We are compelled to confess entire ignorance as to the very nature of matter and energy which form the subject-matter of physics. We do not know what matter is; we do not know what energy is. We are at best able to give only provisional definitions, and *measure* the phenomena without explaining them.

It is possible to state, in some instances, what electricity *is not*. It is *not* "a form of energy," as is very commonly and confidently stated in many so-called "popular works." The following is a conclusive proof of this: Electrical energy is found to be equal, not to quantity of electricity, but quantity multiplied by one-half its potential. That is, the energy of an electrified body depends not only upon the quantity of electricity borne by that body, but also upon its potential; much as the potential energy of a body of water depends, not only upon the quantity of water, but upon the average elevation of the water above surrounding objects. Hence, a quantity of electricity is not a quantity of energy, and electricity is not a form of energy.

It will be seen that in the sense in which it is used above, it is strictly analogous to gross matter, though it differs from it in being apparently imponderable.

LIGHTNING AND THUNDERBOLTS.

To Benjamin Franklin is ascribed the honor of first proving the identity of lightning and electricity. Some notion of the vague ideas which prevailed during the century and a half (not to go farther back) preceding this discovery, may be obtained from the following extracts from a volume issued in London, in 1651, entitled, "Naturall Philosophie Reformed by Divine Light, or a Synopsis of Physics, by J. A. Comenius." In this work electricity receives not the slightest notice, but lightning is confidently and minutely explained under the title of Fiery Meteors. "These" (meteors), he declares, "arise from fat fumes kindled in the air, the principal kinds of which are seven: 1, a falling star; 2, a flying dragon; 3, *lightning;* 4, flying sparks; 5, ignus fatuus; 6, a torch; 7, ignis lambeus." Of the second he says: "This meteor is not so often seen, and, therefore, they that are ignorant of the natural causes thereof, think that the Divill flies." Of the third, he says: "Lightning is fire kindled within a cloud, which, flying from the contrary cold, breaks out with a horrible noise, and for the most part, casts the flames as far as the earth." Its origin is then described as follows: "The World is the Alembick of Nature; the air the cap of this Alembick; the sun is the fire; the earth, the water, minerals, plants, &c., are the things which, being softened with this fire, exhale vapors upward perpetually. So there arise salt, sulphury, nitrous, &c., vapors upward, which, being wrapped up in clouds, put forth various effects, for example: When sulphury exhalations are mixed with nitrous (the first, of a most hot, the second, most cold nature), they endure one another so long as till the sulphur takes fire. But as soon as that is done, presently there follows the same effect as in gunpowder (whose composition is the same of sulphur and nitre), *a fight, a rapture, a noise*, a violent casting forth of the matter; for thence it is, that a viscous flaming matter is cast forth, which presently inflames whatsoever it touches that is apt to flame, and smiting into the earth, it *turns to a stone*, and being taken out after a time is called a thunder-bolt." In this evident, and common, confusion of lightnings with ærolites, the term *thunderbolt* probably originated.

DIRECTIONS FOR AMALGAMATING ZINCS.

New zinc is easily amalgamated as follows. Dip the zinc into a liquid composed of one part by bulk of sulphuric acid and six parts of water, and allow it to remain for two or three minutes, for the purpose of cleansing it of the oxide of the metal on its surface. Then with a spoon pour mercury over the surface of the zinc, and rub the surface with a rag. If the zinc is new, the mercury will readily adhere to it. If the zinc is old, *i.e.*, has been used for a long time in batteries, there will be more difficulty in properly amalgamating it. In this case the zinc should be kept for a considerable time in acidulated water before applying the mercury. The most effectual method, and one which is extremely convenient in most cases, is that in which the zinc is dipped in a solution of chloride of mercury, prepared as follows:

SOLUTION FOR AMALGAMATING ZINCS.

Dissolve 1 part (by weight) of mercury in 2 parts of nitric acid mixed with 4 parts of hydrochloric acid. After the mercury is completely dissolved, add 6 parts of hydro-chloric acid. This solution should be prepared, and the zinc should be amalgamated, out of doors, as both operations give rise to copious nitrous acid fumes which are very obnoxious and corroding. This liquid may be kept in bottles ready for use when required.

SHORT CIRCUIT.

A battery is said to be in *short circuit* when the conductor connecting its poles has a *null* resistance, *i.e.*, when it is very short. To short circuit a line is to connect by a shunt wire the two wires leading from a battery.

DIRECTIONS FOR TESTING THE CONDITION OF A BATTERY AND DETECTING A FAULTY CELL.

A single weak or faulty cell may have the effect of weakening a large battery so that it will be little or no better than a single cell. To detect the faulty cell, connect all the cells in series with the tangent galvanometer in circuit, and note the deflection. Then drop the cells one by one, noting the deflection in each case. A marked change in deflection would indicate that the cell dropped was faulty. If all the deflections are within a few degrees of one another, the battery is in good order.

ANNEALING WIRES.

In splicing copper wires, and in making connections, it will often be found a great convenience to first render them flexible by annealing. This is done by first raising to a red heat a few inches of the wire, and then plunging it into cold water. Brass wire may be treated in the same manner.

DIRECTIONS FOR THE CARE OF BATTERIES, THEIR PECULIARITIES, ETC.

Daniell Battery. Cost about $1.85 per cell. The E.M.F. of this battery is very constant, and varies but slightly with temperature; hence it is well adapted to experiments in electrical measurements. In practice it may be taken as a unit, and others can be compared with it. The British Association has adopted a unit differing very little from this one, and has given to it the name of *volt.* The cell, in which the E.M.F. is exactly one volt, differs but slightly from that of the ordinary Daniell, that of the latter (when the depolarizing liquid used is a solution of sulphate of zinc) being 1.079 volts. It is a cell in which the copper is immersed in a solution of nitrate of copper, and the zinc (amalgamated) in sulphuric acid diluted with twelve times its weight of water.

This is a two-fluid battery, the two liquids being separated by a porous cup. Usually the zinc is suspended in the porous cup either in pure water, or water with the addition of a little zinc sulphate to hasten the action at the beginning. The zinc should not be amalgamated unless, as is sometimes the case, dilute sulphuric acid should be used for the depolarizing liquid. Outside the cup is a thin sheet of copper nearly surrounding the cup, carrying near its top a pocket with holes in its bottom to admit of free ingress and egress of liquid. The liquid in which this is immersed is a saturated solution of sulphate of copper. In the pocket are kept crystals of the same, which are gradually dissolved to take the place of that which is consumed by the action of the battery.

It should be here observed that while the E.M.F. of this battery is quite constant, its resistance is quite variable. It varies from 3 to 5 ohms.

This battery should be thoroughly cleaned as often as once in two months, the plates scraped, and any copper found attached to the inside surface of the porous cup scraped off. In time, copper becomes deposited in the pores of the cups, so that it will be necessary to replace them by new ones. *Never use a cracked cup.*

Gravity Battery. Cost about $1.25 per cell. For description of this battery see § 166, page 191, of Physics. This battery, which is a modification of the Daniell battery is not so well adapted to laboratory use, as it cannot be moved about without disturbing and mixing the liquids.

In using this battery, keep the line between the copper and zinc solutions as sharp as possible. If the blue gets too high, put the battery on short circuit when not in use; this will tend to separate the solutions. Keep the level of the water at least a quarter of an inch above the zinc. The insulation of the copper wire leading up through the liquid from the copper plate should be perfect. Imperfections can usually be remedied by the use of asphaltum paint. To check evaporation, pour a few drops of sperm oil on the surface of the liquid. To prevent *creeping*, dip the parts not in the liquid in melted paraffine wax.

Both the Daniell and Gravity batteries are suited to constant use in circuits of large external resistance, such as in a closed circuit telegraph line. The resistance of the gravity cell is from 2 to 4 ohms.

Leclanché Battery. Cost about $2 per cell. There are two forms of this battery in common use, known as the "disk" and "prism" batteries. The latter is a little more energetic than the former, but less durable, and suffers more in case the battery becomes accidentally short-circuited for a time. This battery is not at all suited to continuous or closed circuit use, as it becomes polarized in a few minutes. For occasional use for a few seconds at a time, such as for annunciator bells, open circuit telegraph, etc., it is admirably adapted. It is used on telephone lines. It will last from two to five years according to the amount of usage. Evaporation from it takes place very slowly, so that no care is needed for months at a time. Its E.M.F. is 1.66 volts; its internal resistance about 1 ohm. If the external resistance is very small, its E.M.F. diminishes rapidly. The battery resists great cold without freezing. Directions for setting up this battery accompany every cell.

Grove Battery. Cost about $2.25 per cell. The depolarizing liquid used in this nitric acid, which give rise to exceedingly obnoxious fumes. The platinum strips are expensive, soon become brittle, and break, and require to be renewed.

Bunsen Battery. Cost of quart cells, about $2 each. In this battery, carbon plates replace the platinums of the Grove battery. To avoid the disagreeable fumes engendered by nitric acid, this liquid is generally replaced by a solution of bichromate of potash prepared as follows:

In one gallon of hot water dissolve one pound of bichromate of potash, and, when cold, add one-sixth its volume of strong sulphuric acid. This liquid is used in the porous cup.

Outside the porous cup the zinc is immersed in *sulphuric acid diluted with ten times its volume of water.*

In diluting sulphuric acid, always pour the acid into the water and never water upon the acid. The reason for this is that water, being considerably lighter than the acid, would float on it, generate great heat at the surface of contact, and the steam arising therefrom is likely to cause trouble.

It is well to renew the liquids of this battery, and reamalgamate the zincs after 48 hours' use. If, when the circuit is broken, a disturbance is heard in the battery, it is an indication that the zincs need amalgamating.

When the battery is taken apart after use, the zincs and carbons should be cleansed in dilute hydrochloric acid, and the carbons should be kept in water for 24 hours. Water should be kept in the porous cups all the time, otherwise sulphate of zinc will crystallize in their pores, and cause them to crack; moreover, cups will in this condition offer great resistance.

Be careful not to spill any of the contents of the porous cup into the outside liquid, as it causes polarization, and greatly weakens the battery.

Make a firm connection with the carbon by turning the screw, which binds it firmly. *Keep all surfaces of contact bright.*

In consequence of its high E.M.F., small resistance, reliability, and (compared with other batteries of high E.M.F.) durability, this is recommended especially for ordinary experimental purposes.

Grenet or Bottle Battery. Ordinary sizes, from pint to two quarts; cost from $2 to $500. E.M.F., from 1.8 to 2.3 volts. Internal resistance about the same as Bunsen. For a short time the working capacity of this battery is greater than any described. The only care which it requires is to *renew the liquids often, and reamalgamate the zincs often.* When the battery is not in use, the zinc must be drawn out of the liquid, otherwise it will be consumed even when the circuit is not closed. Teachers will find this battery very convenient for occasional temporary use. Batteries on the same principle are constructed having several pairs of carbons and zincs attached to a beam, so that they may all be raised from or lowered into their respective jars at the same time, either by hand or windlass. The several elements may be connected abreast or tandem. These are favorite batteries in larger laboratories. These will be made to order at about $4 per cell. *The liquid used in these batteries is prepared in the same manner as the solution used in the porous cups of the Bunsen batteries.*

The amalgamating solution described on page 104 does not injure the carbons, so they may be dipped in this solution with the zincs when desirable with impunity.

General suggestions. Keep batteries of all kinds at as nearly uniform temperature as possible. The separate cells should be well insulated from one another; to accomplish this they should not touch one another, and the shelves or supports should be kept dry. The most suitable wire for connections is the No. 16 copper wire, with braided and paraffined insulation. Zincs ought not to be amalgamated long before use.

EARTH BATTERIES.

In the year 1844 Alexander Vail succeeded in operating Morse's original telegraph line from Washington to Baltimore by means of an *earth battery*, constructed by burying in the earth at the former place a large copper plate, and at the latter place a zinc plate.

The disadvantage of the earth battery is that it is not possible by its means to obtain an electro-motive force above that of a single cell, because any number of pairs of plates that may be used are in effect but one plate, for the reason that they are all virtually placed in a single cell.

DIRECTIONS FOR THE CARE OF AN ELECTRICAL MACHINE.

Always keep the machine in a *dry* place. Rooms where apparatus is kept ought always to be kept well ventilated, especially during the summer-vacation weeks. The glass plate, insulating pillars, and all parts of the machine should be wiped free from dust with a *warm*, *dry* cloth immediately before using it. The plate should be wiped before it is turned to prevent the dust which may be upon it from being wiped off by the rubbers. The amalgam on the rubbers will need renewal very seldom, and only when it becomes roughened upon the surface, or impregnated with dust.

When the plate requires cleaning, it should be done with a woollen cloth dampened with a few drops of spirits of turpentine, and then wiped dry. A machine will always work best when the glass plate and insulators are kept *considerably warmer than the temperature of the room.* This will prevent moisture from condensing upon the insulators, and thereby injuring their insulating properties. If this precaution is properly attended to, the machine will work well in all climates and at all seasons of the year. It is a mistaken notion that electricity escapes through damp air to the earth. It has been proved conclusively that escape takes place over the moistened insulators. The insulators may be warmed by placing the machine in a warm place near a fire or register, or by rubbing them frequently and briskly with warm, dry flannels. When a machine is placed near a fire to warm it before use, it should have the edge of its plate turned to the fire, as the plate is then less liable to crack than if placed with its side exposed to the heat. *Do not breathe on the plate or insulators, or handle them with moist hands.*

When convenient, connect the chain attached to the negative conductor to a gas or water-pipe, when in use.

AMALGAM FOR RUBBERS OF ELECTRICAL MACHINES.

Melt together five parts of zinc and three parts of tin, and pour gradually on the melted mixture nine parts of metallic mercury previously warmed: the whole is shaken briskly till cold, in an iron or thick wooden box; it is then reduced to a fine powder in a mortar, sifted through muslin, and mixed with lard in sufficient quantity to reduce it to the consistency of paste. This preparation should be spread evenly over the surface of the cushion, up to the line formed by the junction of the silk flap with the cushion.

INCANDESCENCE LAMPS.

Voltaic arcs of an illuminating power of less than 100 candles cannot be maintained steady in practice, and are not economical; moreover, on account of the intensity of its light, the arc light is unsuitable for indoor illumination. For small lights it is both simpler and cheaper to employ a thin filament of some infusible conductor, heated to whiteness by passing a current through it. For this purpose lamps are made which consist simply of a curved filament of carbonized paper, or vegetable fiber, about the size of a coarse horse-hair, sealed in a bulb of glass from which air has been exhausted. In the Edison lamp a carbonized filament of bamboo is used. If air were not removed from the bulb, the oxygen would cause the carbon to be burned when it reaches the incandescent state. The Sawyer lamp is filled with nitrogen. The light from one of these lamps varies according to the intensity of the current, from 10 to 21 candles each. The fall of potential in each lamp is from 50 to 91 volts, the resistance from 27 to 137 ohms each, and the intensity of the current necessary to keep up the light is from 0.7 to 1.76 ampères; a light equal to that of from 56 to 115 candles being produced for each horse-power spent on the dynamo-electric machines which generate the current.

DIRECTIONS FOR ELECTRO SILVER-PLATING.

Silver solution. The electrolyte preferred for this operation is a double cyannide of silver and potassium, and for the amateur's purpose may be easily prepared as follows. Take a silver quarter of a dollar, hammer it into a thin sheet, cut it into small fragments, put them into a porcelain evaporating dish, and pour over them four parts of strong nitric acid and one part of water, and heat gently, and dissolve the silver. Use no more acid than is necessary to complete the dissolution. When the metal is completely dissolved, evaporate the liquid portion until a pellicle appears on the surface, when it may be set aside to cool and crystallize. Dissolve the resulting salt, nitrate of silver, in distilled or filtered rain-water, allowing nearly a gallon for each ounce of the salt. Dissolve in nearly an equal bulk of water cyannide of potassium, using about one ounce per pint of water. Add this solution with constant stirring to the silver solution, until a precipitate of cyannide of silver ceases to fall as a white powder. Allow the liquid to settle clear, then pour the clear liquid off, and rinse the precipitate several times with water. Prepare next another solution of cyannide of potassium (about one ounce to the pint), of bulk half a gallon to each ounce of silver cyannide, and add it to the latter with constant stirring, allowing time for dissolution, until all the salt is dissolved. Then dilute with water the whole to about half a gallon to the ounce of cyannide of potassium used. Finally add about one ounce of cyannide of potassium to the solution to form *free* cyannide or an excess of this salt. Caution: cyannide of potassium, called also prussiate of potash, taken internally, is a deadly poison; acetate of iron is an antidote.

Preparation of articles to be plated. This work must be thoroughly done; no ordinary cleaning will answer. Articles made of copper or brass, such as copper coins, brass keys, etc., are best suited for amateurs' work, as they receive the plating most readily. The instrument best suited to this work is the scratch brush, which may be procured of silver platers. It is made of brass wire folded so as to resemble a stick of silk twist. The ends of the stick are cut off so as to leave a brush at each end. If this cannot be easily procured, cork, with soap and water and emery or pumice stone, may be used. Great care should be taken that every crevice is thoroughly scoured. After the article has been cleaned, it should be washed, and a wire attached to it (say a No. 30 copper wire); if the article is a coin, the wire may be pulled around its circumference, and twisted so as to hold it fast. Then, holding it by the extremities of the wire, swill the article through a warm solution of caustic potash or soda, to destroy any grease that may be on the surface, and henceforth do not touch even a finger to the article. Next swill it through dilute sulphuric acid, and then immediately plunge it into a "quicking solution" prepared as follows: Dilute an ounce of nitric acid with three times its volume of water, and then add slowly mercury, stirring as long as the metal is dissolved; then add about half a pint of water. When the article (in course of a few minutes) becomes uniformly white, remove it, and swill it through clean water, and quickly immerse it in the electrolyte and connect the wire by which it is suspended with the negative pole of the battery. Likewise, in the electrolyte, about an inch from the article to be plated, suspend from the positive pole of the battery a strip of thick silver foil. The surface of the foil submerged in the electrolyte should have about the same area as that of the article to be plated. It is well to keep the article to be plated moving up and down or sidewise, and parallel with the positive electrode. If the deposit is dark colored, it is probably an indication that the strength of the current is too great. This may be reduced either by separating the two electrodes farther from each other, or by introducing a shunt of suitable resistance. A single Bunsen cell will answer for the battery.

Burnishing. Articles when taken from the electrolyte appear dull white or straw-colored, and entirely lusterless. They now require to be burnished in order to give them the usual appearance of silver. For the amateur's purpose this may be well enough done by rubbing them with a scratch brush such as described above, and subsequently with pulverized whiting, and finally with rouge.

The directions here given both for electrotyping and electroplating are in accordance with the author's practice for many years.

DIRECTIONS FOR ELECTROTYPING.

For convenience, we assume that the reader possesses the author's "complete set of apparatus for electrotyping," and the directions given will correspond thereto. The directions will be given in such detail that no one who will faithfully follow them need fear a failure. First, place the moulding-case on a hot stove, or over a Bunsen or alcohol lamp, in a perfectly horizontal position, and melt in it enough prepared wax to just fill it. If, when melted, any air bubbles float on its surface, they should be scraped off with a knife or splinter of wood. Allow the wax to cool and solidify. If you have succeeded in obtaining a smooth, even surface of wax, you may proceed with the work; otherwise, it should be re-melted. Allow the wax to stand for several hours and become quite cold; then apply, with a brush, plumbago to its surface for at least ten minutes, so as to obtain a highly polished surface. This part of the work must be thoroughly done; and in every case when plumbago is applied, time and patience must be bestowed upon the work, and a plenty of plumbago used. Go over the surface *many times* with the brush, not bearing on heavily so as to scratch the wax. When done, carefully remove any loose plumbago not adhering to the surface. Now cover the surface of the wax with a thin sheet rubber, smoothly laid on. Lay on this wax a medal, coin, etc., which you wish to copy, with the surface which you wish to copy next the rubber. Cover the whole with a board of the same size as the moulding case. Place the whole under a letter-press (preferably) or in a vise, and press the copy a little way into the wax, so as to obtain roughly a general but not a distinct impression of the copy. The impression cannot be very distinct in consequence of the intervention of the rubber. Now remove the rubber from the wax, and again carefully apply plumbago with the brush to that part of the wax which has received the impression. Now lay the copy carefully into the imperfect mould, fitting it carefully to it in the same position that it originally occupied. (The rubber is not used in this case.) Cover with the board, replace it in the press or vice, and once more subject it to pressure not too great, and obtain a distinct and well-defined impression of the copy. If you have not succeeded in doing this to your satisfaction, re-melt the wax and repeat all the foregoing. The plumbago which the wax has received will do no harm. On the other hand, it is rather a benefit, and the same wax may be used an indefinite number of times.

Once more apply the plumbago carefully, patiently, and thoroughly to the mould, being careful not to injure it, and at the end carefully remove all superfluous plumbago. Next take the stout copper wire, flattened at one end and bent into a loop at the other end, and force the flattened end into the wax at the upper (*i.e.*, the end of the moulding-case, which is pierced with two holes) central part, so that when this wire is in place it will be nearly parallel with the surface of the wax. With a finger press the edges of the wax where the wire enters it firmly against and around the wire, so as to heal up the wound made in the wax as well as possible. Now apply plumbago to the edges of the wound, so as to make a good electrical connection between the wire and the plumbago surface. Bear in mind in all that you do that plumbago is a conductor of electricity, and wax is a non-conductor.

Next, flow the whole plumbago surface with alcohol, then allow it to drain off, and immediately flow the surface with some of the solution of sulphate of copper described below, and sift over the whole surface plentifully fine iron filings. Allow it to stand for from two to five minutes, during which time there ought to be a tolerably brisk chemical action; after which thoroughly rinse the filings from the wax, by pouring on it a plenty of water. If now the entire surface appears of a bright copper color, you may proceed as follows: With the point of a knife scratch a shallow furrow in the wax surface completely around it, near the edge of the moulding-case, including the copper wire which has been forced into the wax. You thereby make this insulated surface an electrode, and exclude all the remainder on which you do not wish copper to be deposited by electricity. Quickly suspend the moulding-case by means of hooks from a wooden rod laid across the mouth of the glass jar. Parallel with this, next the plumbago surface, and as little way from it as practicable, not allowing them anywhere to touch each other, suspend the copper plate from the brass rod by means of hooks. Connect the *negative* pole of the battery with the copper wire, which is plunged into the wax. Connect the *positive* pole with the screw cup at the end of the brass rod. A single Bunsen cell will answer for the battery, though two Daniell's cells connected abreast are preferable, since they furnish a more uniform current.

The solution of copper sulphate which is to be used for the electrolyte should be prepared as follows: Add commercial sulphuric acid to water till it has a specific gravity of 1.05, then dissolve copper sulphate in this liquid till it has a specific gravity of 1.114. This solution should be prepared before the wax mould is made.

A sufficiently thick deposit of copper ought to be obtained in from 24 to 48 hours. Then it may be carefully stripped off from the wax. If the exposed surface of the copper electrotype, when it is adhering to the wax, appears warty or quite rough, it is an indication that the battery power is too strong. If it is desired to make use of the electrotype, it should be backed with lead by some experienced electrotyper, inasmuch as amateurs are not likely to have facilities for doing it properly. The electrotypes may then, especially if they are copies of medals or coins, be silver-plated or gilded, and preserved in the school cabinet.

POTENTIAL AND ELECTRO-MOTIVE FORCE.

The conception of *potential* and *electromotive force* are of the highest importance in the theory of electricity. They find convenient analogues in hydrostatics in the terms *head* and *pressure.* Thus, the velocity of the flow of water in the uniform pipe *AB* (Fig. 17) of a given length, or the strength of the current, *i.e.*, the rate at which water issues from *B*, depends upon the hight or *head* of water *CD*, or, which is equivalent, the *hydrostatic pressure.* Imagine that *DE* represents the copper plate of a battery, and *B* the zinc plate, and *AB* a wire of definite length connecting them; then the velocity of the flow of electricity in the uniform wire, or the strength of the current, depends upon the difference of potential at *A* and *B*, or, which is equivalent, the *electro-motive force.*

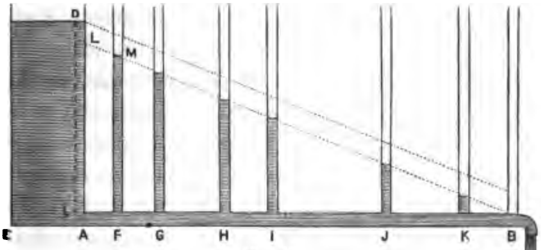


Fig. 17.

If at intervals, as at *F*, *G*, *H*, etc., the water-pipe is tapped, water will spurt from the holes with varying hight, or, if tubes are inserted at these points, the hight at which water stands in these tubes will be an exact gauge of the head of water, which would be necessary, at any one of these points, to maintain the same strength of current in a pipe extending from that point to *B*. In other words, the hight of the water at these points measures the hydrostatic pressure at these points. The line *LB* connecting the surfaces of water in the several tubes shows that in the uniform tube *AB* there is a constant and regular diminution of head for equal intervals; and for unequal intervals, the diminution is exactly proportional to the lengths of the intervals.

If at intervals, in a battery wire, sensitive electrometers (*potential meters*, such as have been brought to a high degree of perfection by Sir William Thomson and others) are applied, the potential at the different points can be accurately measured (and compared), and the potential at any point ascertained which would be necessary to maintain the same current between that point and the zinc plate of the battery. Morever, it is found that in a uniform wire the falling off of potential from the copper to the zinc plate is constant and regular.

If the tube *AB* were lengthened, there would be a similar but slower subsidence of head; for example, the water in tube *F* will stand a little higher than *M*, and so with each of the others; the increase of friction of the water against the sides of the tube attending the increase of length would diminish the velocity of the flow, and hence diminish the strength of the current. If the battery wire is lengthened, and different points tested, the fall of potential will still be found to be both constant and regular, but less rapid, and the strength of the current correspondingly weaker.

If any portion of the pipe *AB*, say the portion between *I* and *J*, is made narrower, or the interior is roughened so as to increase the friction of that portion, the head in the tube *I* and all the preceding tubes will be raised; but in *J* and the subsequent tubes it will be lowered, and the velocity of flow diminished. If a smaller wire, or an iron or platinum wire, is substituted for any portion of a uniform copper wire, the difference in potential between every two points, one above and the other below the substitute, will be increased, and the strength of current will be diminished.

As the direction of a liquid current is always from places of higher head to places of lower, and the rate of flow is proportional to the rate at which the head decreases from point to point, so the direction of an electric current is always from places of higher to places of lower potential, and the intensity of current is proportional to the rate at which the potential decreases from point to point.

Although the analogy between hydrostatic and electrostatic phenomena in many particulars seems well nigh perfect, yet the student should be apprised that it has its limits, beyond which he must not attempt to push it.

A tube *op*, Fig. 3, p. 9, will be furnished if desired (at a cost of seventy-five cents), which may be connected to the tube *h* of the "eight-in-one" apparatus. This tube is tapped by holes at intervals along its length, and the streams issuing from them show, by the hights attained, the pressure at their respective points. It will be seen that this attachment may be used to illustrate an important principle in *hydrostatics* in addition to its great value as a means of presenting the subject of potential in an easy and intelligible manner.

THE DYNAMO-MACHINE REVERSIBLE.

Clerk Maxwell, being asked by a scientist what was the greatest scientific discovery of the last quarter of a century, replied, "That the Gramme machine is reversible." That is, it can be used interchangeably as a machine to develop electric energy, or a machine to transform electric energy into the energy of mechanical motion. He had in mind their possibilities in the near future of utilizing the great wasted energies of nature, such as those of our great waterfalls, tides, winds, etc. For, by means of the Gramme machine and dynamo machines generally (for nearly all are reversible), these various forms of energy may be transformed into the energy of an electric current, and conveyed or transmitted by conducting wires to different points where power is required; and there, as these currents pass through a second dynamo, cause the armature of a second machine to rotate in the opposite direction to the first, and thus the electric energy is reconverted into motive power, which, by any well-known means, may then be made to do nearly every species of work. The discovery referred to was made by Gramme himself in the year 1872. The dynamo machine is really the only *practical* electro-motor known, no other form being able to compete successfully and economically with power derived from the consumption of coal.

A good illustration of the reciprocal action of the dynamo on a small scale is found in the original Bell telephone, in which the transmitter, being made to vibrate by the voice, generates electric currents, thus acting like a generating dynamo; while the receiver, an instrument which is an exact duplicate of the generator, converts the energy of these currents into mechanical motion, thus acting like an electro-motor.

SECONDARY OR STORAGE BATTERIES.—REVERSIBILITY OF ELECTROLYSIS.

The voltaic cell is reversible. For example, during the working of a Daniell's cell zinc is dissolved, and copper is deposited upon the electro-negative plate. Now, if we take such a cell, connect in opposition to it a battery of superior E.M.F., and drive electric currents back through this cell, the whole action will be reversed,—*copper will be dissolved and zinc will be deposited; and thus energy is stored in the cell.* But, as usual, the work of the battery is performed *against resistance*, in overcoming the polarization force or E.M.F. of the cell. *Polarization is of the nature of a counter E.M.F.* It is precisely this polarization force that we have to contend with in every voltaic cell, and which we seek to neutralize by the aid of polarization batteries, and sometimes storage batteries. Note that it is *an electrical storage of energy, not a storage of electricity*,—two very different things. The amount of energy which can be stored increases with the size of the electrodes. If, instead of platinum, two pieces of sheet lead rolled up, covered with a coating of red lead, are used as electrodes, dipping as before into dilute sulphuric acid, and the electrodes are connected with a powerful voltaic battery, or, better, with a dynamo-electric machine, the positive electrode becomes by electrolysis peroxydized (PbO_2) by the oxygen which is liberated, while the negative electrode is deoxydized by the hydrogen. The plates may remain for many days in this condition, and will furnish a current until the two lead surfaces are reduced to identical chemical state. The E.M.F. of such cells may even attain from 2.38 to 2.72 volts (S. P. Thompson). The internal resistance of a cell whose surface of electrodes is 300^{qcm} is about 0.006 ohm. Planté has arranged batteries of such cells so that they can be charged in parallel arc and discharged in series, giving currents of extraordinary strength. Two hundred such cells would give an E.M.F. of about 240 volts.

By means of a dynamo-electric machine energy may be stored (though not as yet economically) in these batteries.

Electrolysis is reversible. If water is decomposed for a time between neutral electrodes, such as platinum plates (see Exp. 4, p. 194, Physics), and the battery is withdrawn from the circuit and replaced by a sensitive galvanometer, a deflection of the needle will show that a current is flowing in the opposite direction to the primary or electrolyzing current. It is evident that the electrolyzing current polarizes the electrodes in the electrolyte, and that energy is thus stored in the cell. *Polarization constitutes a source of enery.* When the wires are joined, this polarization causes a current to flow of sensible duration, and the platinum electrodes become depolarized. A sensible time is required to bring these electrodes to a maximum condition of polarization which a given E.M.F. can produce. (Compare the work done and energy stored in electrolysis to that which is accomplished in raising a stone, § 92, Physics.)

Devices for thus storing up energy by electrolysis, and liberating it when desired in the form of electric current, are called *accumulators,* sometimes *secondary batteries.* For example, the energy of chemical decomposition may be stored up during the day-time ; and this energy, reconverted into electric energy, may feed electric lights at night. Or these batteries, having been charged by a dynamo, may be transported to lecture-halls, workshops, etc., where powerful currents may be needed for any purpose. They may also be used as governors (much as fly-wheels in steam-engines) to regulate the constancy of the current fed out to the work, by interposing an accumulator between the dynamo and the work done. Those who have watched street arc-lights for a short time must have learned by the fluctuating light that the current is quite inconstant. If an accumulator were placed in circuit, it would furnish light during the time there is a subsidence of current from the dynamo, and, on the other hand, it would resist any sudden effusions of intensity.

My pupil, A. M. Bullard, prepared a storage cell at his home, charged it from a battery of his own device (see description in Electrician of June, 1884), brought it to school, and worked with much energy various apparatus belonging to the school, such as electric-bells, electro-motors, etc. The following is a description of the accumulator in his own words : —

" My storage battery was made by covering twenty lead plates, each an inch wide and six inches long, with a thick paste formed of red oxide of lead and dilute sulphuric acid (1 to 12).

"The plates were cut from thin sheet lead, with a lip projecting upward from one corner about five inches. After having covered both sides of the first plate with the red oxide mixture to the depth of about one-sixteenth of an inch, I enveloped it from end to end in a piece of cotton cloth an inch wide and twelve inches long. I provided myself with twenty-one thick sheets of card-board the size of each plate. I laid the first prepared lead plate on a piece of the card-board, with the ear of lead at the left. I placed another card-board and a second plate, with the ear at the right, on top of that, and so on, alternating, until all twenty leads were in the pile, which I strapped firmly together by means of large, elastic bands.

" I next placed them in a glass fruit-jar with a glass screw-cover, and filled the jar two-thirds full of dilute sulphuric acid, in proportion the same as that used in making the lead paste. The lead-connecting strips on each side were bent over the edge of the jar and clamped down by the cover. Of course, each set of lips was kept apart. I next passed a binding-post through the ends of the ten strips on one side of the jar, and another in the same way through the rest. These posts formed the positive and negative poles of the battery. After leaving it to absorb the water for a short while, I connected it to an eight-cell bi-chromate of potash battery [joined in series] for about fifteen or twenty minutes, noticing which poles of the storage battery I connected with positive and negative poles of the primary battery. The current I received from the charged cell at first was not as strong as afterwards, when I had charged and discharged it several times.

"The poles of the storage cell were changed several times when first forming the battery; but after it had been connected with the primary battery five or six times, I found it best always to use the same poles in charging. I made afterwards four of the same pattern and connected them up in series as in a regular battery, and the effects were much more powerful."

ODDS AND ENDS.

Gravitation on the sun is about twenty-seven times as great as on the earth.

According to Helmholtz, the mechanical work performed in the circulation in a man's body is 70,000^{kgm} per day, that of respiration 11,000^{kgm}. Allowing 19,000 for all other processes, the interior work of a man would be 100,000^{kgm} per day.

The specific gravity of actylene (a hydro-carbon), the lightest liquid known, is 0.45.

F. Rosetti finds the temperature of the flame of the Bunsen burner to be, in the external envelope, 1350° F.; in the violet portion, 1250°; in the blue, 1200°.

The highest heat of a common wood fire is estimated at 1140° F.

A mixture of 9 parts of phosphate of soda, 6 parts of nitrate of ammonia, and 4 parts of nitric acid, is a freezing mixture which will cause, it is said, a fall in temperature of 71° F.

In 1745, Cuneus, a philosopher of Leyden, discovered what has since borne, not his name, but that of the town in which he lived, the *Leyden jar.*

"The discharge of an induction coil giving a one-fourth inch spark is the maximum that can be taken with safety."—GORDON.

The great majority of substances in nature are diamagnetic.

The metal which ranks next to mercury in fusibility is the newly-discovered element *gallium*, which fuses at about the same temperature as ice.

"The smallest shock sensible to a person is decided to be produced by a charge of 0.7 of a microfarad, and 0.8 of a microfarad is now adopted as the least charge which should cause the ignition of a safe fuse." — ABBOTT.

"The resistance in ohms of the human body averages about as follows: From one hand to the other through the body, hands dry, over 10,000 ohms. Same with hands wet, 6000 ohms." — DOLBEAR.

The resistance of a Bell telephone coil is about 75 ohms.

Prof. G. S. Ohm was born March 16, 1787; died July 7, 1854.

The names of the units employed in electrical science have been coined out of the patronymics of those who have distinguished themselves in this science.

Motion in the field of a magnet gives rise to currents of electricity. This fact is embodied in the following lines from "Blackwood's Magazine": —

"Around the magnet, Faraday
Is sure that Volta's lightnings play, —
But how to draw them from the wire?
He took a lesson from the heart:
'Tis when we meet, 'tis when we part,
Breaks forth the electric fire."

In the collection of the Ecole Polytechnique the small natural magnet belonging to M. Obelliane is remarkable as being, with regard to its weight, by far the most powerful magnet known. It can lift forty times its own weight.

In the South Kensington Museum is an artificial magnet made by M. Jamin, of thin plates of steel, which can lift 200^k.

The largest electro-magnet, according to Humboldt, is that in the Physical Institute of the Greifswald University. It is of horse-shoe shape. The diameter of the cylindrical core is 8 in., its total length 9 ft., and its weight 1381 lbs. Total weight of core and coil, 1986 lbs. The whole rests on wheels. The current is generated by 54 Grove cells. With this powerful instrument a great variety of experiments can be performed. When a copper cylinder containing 40^g of Wood's fusible metal (melting at about 70° C.) is rotated between the poles, it melts in less than two minutes. By using a sugar solution in a tube 8 in. long, the plane of polarization changes from red to light-blue on reversing the poles. The magnetic or diamagnetic action of liquids, gases, and flames can be made visible to a large audience. A rotating copper disk 10 in. in diameter, which can be rotated rapidly in a vertical plane by means of a weight, is almost stopped on closing the current.

"An ordinary telegraph wire could convey the whole energy of Niagara Falls, and convey it to any distance; but the wire would be at so high a potential that sparks would fly from it into the air."—DANIELL.

"It is practicable with ordinary telegraphic wires insulated in the ordinary way, and with a 16 h.p. dynamo, to drive a 6 h.p. electro-motor at a distance of 30 miles."—DANIELL.

When the needles of an astatic needle are precisely equal in strength, they will set at right angles to the magnetic meridian.

"We are ignorant of the true linear velocity of an electric current. It is quite possible that the velocity of electricity in a telegraph wire may be exceedingly small, less (say) than the hundredth of an inch in an hour, though signals, *i.e.*, changes in the state of a current, may be propagated along the wire many thousands of miles in a second." — MAXWELL.

In 1869 the wires between Cambridge, Mass., and San Francisco were connected, making a circuit of over 7000 miles, with thirteen repeaters. The time required for what is usually denominated the electric flow of the current was 0.74 of a second, or, deducting the time required to open and close the repeaters, about 0.3 of a second, or at the rate of 1,400,000 miles a minute, or 23,333 miles a second.

We are told of an instance in which a gentleman coiled up the end of his lightning rod, and put it into a bucket in his cellar, thinking that the water would extinguish the lightning.

A steel magnet brought to a white heat totally loses its magnetism, and will not recover it when cooled.

It is suggested that magnetic oxide of iron is to be preferred to iron filings in experiments illustrating the magnetic lines of force. It is easily pulverized to any desired degree of fineness.

The resistance of iron wire increases about 0.35 per cent for each additional degree Fahrenheit. The resistance of copper wire increases about 0.21 per cent for each additional degree. The conducting power of carbon is much lower than that of the metals, and instead of decreasing, as in the metals, with a rise in temperature, it increases.

The first magneto-electric machine was constructed in 1833 by Pixii.

"The currents circulating in the telephone are perhaps a thousand million times less than those which would cause an ordinary electro-magnet to attract a piece of soft iron close to its pole with a force equal to a few grains." — JENKIN.

Clerk Maxwell's electro-magnetic theory of light is briefly this: Electro-magnetic induction is propagated through space by strains or vibrations of the same ether which conveys the light vibrations; or, in other words, light itself is an electro-magnetic disturbance.

In the propagation of both light and electro-magnetic induction, it can be shown experimentally and mathematically that the disturbance is at right angles to the direction of propagation.

The velocities in air of light and of electro-magnetic induction are sensibly equal.

"Wife!" exclaimed a man in ——, "I don't see how they send letters along those wires without tearing them all to bits." "Get along, you ignoramus," replied the wife; "they don't send letters along the wires; they only send the writing in a *fluid state.* Don't you see the ink bottles all along the poles?"

"Mr. Latimer Clark telegraphed through the Atlantic cable with a battery formed in a lady's thimble; and Mr. Collett said, 'I have just sent my compliments to Dr. Gould of Cambridge, who is at Valentia, with a battery composed of a gun-cap with a strip of zinc excited by a drop of water the simple bulk of a tear.'" — LONDON TELEGRAPH JOURNAL.

The temperature of a furnace may be determined approximately by means of an observation of the resistance to a current of electricity of a platinum wire placed in the furnace.

"We have reason to believe that water is not an electrolyte, and that it is not a conductor of the electric current. It is exceedingly difficult to obtain water free from foreign matter. Kohlrausch, however, has obtained water so pure that its resistance was enormous compared with ordinary distilled water. When exposed to the air for 4.3 hours its conductivity rose 70 per cent, and in 1060 hours it was increased nearly forty-fold. The oxygen and hydrogen which are given off at the electrodes in so many experiments on water containing foreign ingredients are, therefore, not the ions of water separated by strict electrolysis, but secondary products of the electrolysis of the matter in solution." — MAXWELL.

The E.M.F. of the electrical machine is the excess of the potential of the comb above that of the rubber. Discharges of electricity between two metallic balls, through air or other gas of ordinary density, occur in sparks. If the experiment is conducted in a glass vessel from which air may be exhausted by an air-pump, it is found that, as the density of the gas diminishes, the sparks become smaller and more frequent, till at last there *appears* to be a continuous flow; at the same time the E.M.F. necessary to produce the discharge diminishes until the pressure is reduced to that of 3^{mm} of mercury. If the exhaustion is carried further, the E.M.F. necessary to produce discharges increases, the discharges become less frequent, and the sparks more powerful, until, in the highest vacuum yet obtained, the E.M.F. required to produce a spark between electrodes 6^{cm} apart would cause a discharge through a distance of 20^{cm} of air of ordinary density. It would, therefore, seem as if a perfect vacuum would present almost insuperable resistance to the passage of electricity.

The resistance of a cubic meter of glass at 200° C. is 227,000 ohms; at 400° C. it is 735 ohms.

The smaller the distances between the surfaces, and the greater the area of the surfaces of the Leyden jar, the greater is its capacity.

A theory called the "Kinetic theory of matter" is now strongly advocated by leading physicists. It maintains that *all the properties of matter are merely attributes of motion.*

"Electrical resistance is a property that differs very widely in degree in different substances. The best conductor known is pure silver. One of the worst is gutta percha, the resistance of which is no less than 850,000,000,000,000,000,000 times as great as that of pure silver. Substances commonly termed insulators are in fact nothing more than substances having a very great specific resistance. The terms *conductor* and *insulator* are, therefore, entirely relative and not in any sense absolute in their meaning, and it will be well for the student to consider all bodies as *conductors having more or less specific resistance*, as the case may be. This view of the matter will materially assist him hereafter in forming a clear and distinct conception of the nature of electrical action." — POPE.

Just as this book goes to press, the announcement is made that the long-sought-for anti-induction telephone and telegraph wire has been discovered. It consists of an anti-induction shield composed of a combination of magnetic and diamagnetic metals rolled into very thin sheets, strips of which are wound spirally around the ordinary wire, and insulated therefrom. If it will do what is claimed for it (by those who ought to know), it is one of the most important electrical inventions that has been made for some years.

PART III.

GENERAL REVIEW OF PHYSICS, WITH HINTS TO TEACHERS.

CHAPTER I.

PROPERTIES OF MATTER.

§ 1, p. 1. The pupil may be informed that, though the definition here given of an *experiment* harmonizes with its etymological signification and with the general spirit of this book, yet it is frequently used as a synonym for *illustration* or *proof.*

P. 3, Exp. 5. The apparatus furnished for this experiment is so sensitive that sufficient air can be drawn from the globe by suction with the mouth to cause the beam to tip perceptibly. A change in weight will be still more perceptible if, after exhausting the air by suction, a person were to condense air in the globe by blowing into it, and then closing the stop-cock.

§ 4, p. 4. "The molecules of the same substance are all exactly alike, but different from those of other substances. Molecules are unalterable by any of the processes which go on in the present state of things, and every individual of each species is of exactly the same magnitude as though they had all been cast in the same mould, like bullets, and not merely selected and grouped according to their size, like small shot.

They are, as we believe, the only material things which still remain in the precise condition in which they first began to exist." — MAXWELL.

§ 5, p. 6. The pupil may be aided in applying this theory to the condition of things supposed to exist, for instance, in the test-tube of § 4 filled with water, by imagining that he is looking at a dense flock of birds in the air. The flock remains at rest, but the individuals which compose the flock are in rapid motion, frequently hitting and bounding away from one another. At the same time he sees the whole atmosphere filled with birds of a different hue. These birds, like the former, are in constant motion. Some are constantly entering the space occupied by the flock, and some are leaving it, while all are jostling against one another. The latter birds are nowhere nearly so thick (*i.e.*, there are not so many in a given unit of space) as those which compose the flock, but they are thicker in the space occupied by the flock than in the space outside the flock, partly because their escape from this space is impeded by the presence of the birds of the flock, and partly because of some mutual attraction or affiliation.

The birds constituting the flock may represent the molecules composing the body of water in the test-tube; while the birds of different hue may represent the air molecules. Beware of the common error of supposing that the latter are *smaller* than the former, as in the oft-given but fallacious illustration of "apples, marbles, and bird-shot." Apprise the pupil of the fact that air in water is in a comparatively condensed state; in other words, that a tumbler filled with water contains more air than it would contain if no water were in the tumbler.

§ 7, p. 7. LAW OF AVVOGADRO. — *All gases (at the same temperature and pressure) consist, within equal volumes, of equal numbers of molecules.*

Exp. 2, p. 10. This may well be made a home-experiment, and performed as follows: On two piles of books about 10^{cm} apart support a tin basin containing about a liter of ice-water and a few lumps of ice. Between the piles and under the basin place a lighted candle, so that the tip of the flame will just touch the basin. The books, besides serving as a support, will protect the flame from currents of air. In 10 or 15 minutes the bottom of the basin, except a small area immediately over the flame, will be covered with large drops of water, and a stalactite of carbon will depend from the basin immediately above the flame. After the pupil has performed this experiment he should be plied with such questions as follows: —

Whence came the water and the carbon? What purpose does the ice-water serve? Whence comes the water frequently found on sweating ice-pitchers? How do you know that the water found on the bottom of the basin did not come from the same source? Would the *heat* of the flame tend to increase or retard this condensation? Does carbon always rise from a burning candle flame? Why does it collect in such abundance in this case? What are the ashes of the candle?

§ 11, p. 12, Exp. 1. Inasmuch as the success of this experiment depends frequently upon the condition of the apparatus and the state of the weather, the following substitute will be found very convenient: Take a cork about 1^{cm} in diameter, and cut it transversely into slices about 1^{mm} thick. Then take four cambric needles, break them in the middle, rub each piece two or three times in the same direction across the same pole of a magnet, and thrust each piece perpendicularly through a cork slice, leaving one extremity level with the surface of the cork. Be sure that the ends which are inserted in the corks are all the same poles, *i.e.*, all S. or all N, poles. Fill a bowl or goblet with water to the brim, and float the slices on the surface of the water, with the projecting part of the needle immersed in the water. Holding a bar-magnet vertically, approach the center of the surface of the water with one of its poles, and the slices of cork will sail along the surface, either collecting under this pole of the magnet or receding from it. Reverse the pole of the magnet, and the phenomenon will be reversed.

§ 17, p. 18. The native of Borabora who called hail "white stones" spoke the simple truth. Ice is *stone*, *a mineral*, in every sense which these terms imply. In the year 1739, at the wedding of Prince Gallitzin, the Russians built for him a house of large blocks of stone. All the furniture of the house, even to the nuptial bed, was made of the same stone; and the cannon and mortars which were fired in honor of the day were constructed of the same. The mineralogical name of this stone is — ice.

§ 17, p. 20. "According to Pictet, oxygen is liquefied at 320 atmospheres pressure and – 140° C.; and then, upon allowing a jet of this liquid to escape into the air, the escaping jet of liquid oxygen becomes extremely cold and is partly solidified. Hydrogen treated in a similar manner, under a pressure of 650 atmospheres, appeared as a steel-blue stream of liquid, the light reflected from which, being partly polarized, revealed the presence of solid particles in the liquid, while the tube of exit became blocked with solid hydrogen." — Daniell.

Full accounts of the liquefaction and solidification of the "permanent gases" can be found in the Popular Science Monthly, Scientific American, and Nature, of the year 1878.

§ 21, p. 22. It may be demonstrated geometrically that a particle placed anywhere, as *A*, *A′*, *A″*, etc., Fig. 18, within a homogeneous spherical shell will be in equilibrium. Consequently, if the earth were such a shell, a body placed anywhere within it would remain at rest. Hence, it follows that if the earth were a homogeneous solid sphere, the weight of any body within it, as *B*, Fig. 18, would vary as its distance from the center *C*, and would be entirely independent of the external shell, as *ED*.

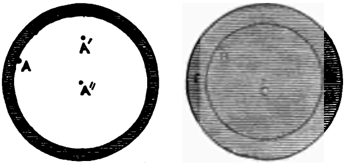


Fig. 18.

P. 25. In performing Exp. 1 notice the difference in the crystals formed on the thread and those formed on the bottom of the vessel. The latter are said to be *tabulated.*

In performing Exp. 2 watch the growth of the crystals, looking through a simple microscope. In their note-books pupils may draw figures of the crystals formed, both of a single crystal, and of a group of crystals, selecting the most interesting.

§ 25, p. 26. Repeat the experiment with the bar-magnet and floats (p. 133), and notice that when the floats are attracted to one end of the magnet, through the influence of their polarity, they arrange themselves in some regular geometrical form, *i.e.*, in squares, pentagons, hexagons, etc. This phenomenon is as significant as it is interesting.

§ 28, p. 31. *Strain.* In physics any alteration of size or shape whatever is called a *strain.* It includes all alterations in volume, — as compression or expansion of gases, — all twistings and bendings, and all extensions, as a piece of stretched india-rubber.

§ 30, p. 31. *Viscosity.* "If a constant stress causes a strain or displacement in the body, which increases continually with the time, the substance is said to be *viscous.*

"When this continuous alteration of form is only produced by stresses exceeding a certain value, the substance is called a solid, however soft it may be. When the very smallest stress, if continued long enough, will cause a constantly increasing change of form, the body must be regarded as a *viscous fluid*, however hard it may be.

"Thus, a tallow candle is much softer than a stick of sealing-wax; but if the candle and the stick of sealing-wax are laid horizontally between two supports, the sealing-wax will in a few weeks in summer bend with its own weight, while the candle remains straight. The candle is therefore a soft solid, and the sealing-wax a very viscous fluid.

"What is required to alter the form of a soft solid is a sufficient force; and this, when applied, produces its effect at once. In the case of a viscous fluid, it is *time* which is required; and, if enough time is given, the very smallest force will produce a sensible effect, such as would require a very large force if suddenly applied." — MAXWELL.

§ 33, p. 33. *Adhesion.* In both experiments with the water and the mercury it is important that the glass slip should be quite clean. It is well, previous to each experiment, to wipe the glass and the surface of the mercury with a dry, clean cloth, so as to remove any oxide of mercury which may rest upon their surfaces.

CHAPTER II.

DYNAMICS.

P. 47. If the author's "Seven-in-one" apparatus is substituted for the Magdeburg hemispheres, no air-pump will be needed, and no mystery, which its action and the necessity for removal of air might cause, will be introduced. If the piston of this apparatus is forced into the end of the cylinder, and the stop-cock is closed so as to prevent air entering the apparatus, a weight of two or three hundred pounds may be suspended from the piston without drawing it down. But if air is admitted, by turning the stop-cock so as to press on both sides of the piston, it will quickly descend.

§ 46, p. 48. *Apparatus for exploration of pressure in the interior of a liquid mass.* A very convenient substitute for the apparatus represented in Fig. 27 is a glass manometer tube, represented in Fig. 19. Mercury or some lighter colored liquid may be used in the tube: the lighter the liquid the more sensitive will be the instrument. Connecting a short rubber tube with the extremity *a* of the glass tube, and bending it in different directions, pressure in all directions and at different depths can be explored and compared.

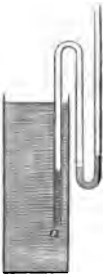


Fig. 19.

§ 50, p. 57. *Mariotte's Law Apparatus.* In the preparation of this apparatus for use there is usually some difficulty in getting the surfaces of the mercury in the two arms of the tube on the same level. This may be accomplished, however, after a few trials, by tipping the tube, and either admitting small bubbles of air into the short arm, or excluding it therefrom, as the case may require.

The base of the tube (Fig. 38) is sufficiently large to receive the tube (Fig. 39), hence it will answer for the jar *B* in Exp. 2.

§ 52, p. 61. In using the apparatus illustrated in Fig. 46, very likely the stream issuing from the longest tube *d* may not quite reach the level of the top of the other streams. This is to be explained as the result of the friction against the sides of the longer tube, the friction increasing with the length of the tube.

§ 53, p. 64. In using the Seven-in-one apparatus as a hydrostatic bellows, the piston should be forced into the cylinder, and the space between the piston and the end of the cylinder should be filled with water. This may be done by temporarily removing the rubber tube. If there is any difficulty in removing the air from the tube, so as to allow the water to enter it, the tube may be first filled with water, and, while in a nearly horizontal position, be connected with the union-screw, and afterwards raised to a vertical position.

§ 55, p. 67. In using the improved Pascal's Vases, support the base upon the side of a water pail. Attach to it first the vase corresponding to *C*, Fig. 52. Suspend the disk *d* from one arm of the balance-beam, and the counterpoise from one of the holes in the other arm. Pour water slowly into the vase, allowing it to trickle down its side, at the same time elevating the nut on the rod supporting the disk so as to keep it on a level with the surface of the water. Continue to pour water until it forces the bottom off. Then remove the vase from the base and substitute the cylinder *A*. Now, if water is carefully poured into the cylinder, it will be found that the bottom will be forced off at the instant the surface of the water reaches the nut.

§ 63, p. 80. *Specific Gravity.* One of the pans of the balances furnished by the author has a hook beneath it, from which specimens are suspended. The gram weights accompanying the same are made of brass, and the centimeter and milli~~meter~~ weights of aluminum; and the whole are neatly mounted in a block of wood.

The pupil will soon discover (however simple it may seem to him before trial) that weighing is an art at which he will find himself quite awkward at first. He will learn it better by experience than precept. A few directions, like the following, will be serviceable to him.

Always ascertain the weight of a solid in air, before it is wet by the liquid.

When weighing in a liquid, see that the solid is completely immersed, and nowhere touches the vessel holding the liquid.

While changing the weights, hold the beam with one hand, that it may not fall from its support and suffer injury.

It is not desirable to use specimens weighing in the air more than from 5^g to 8^g. Specimens even lighter than these will answer just as well. After weighing one or two specimens, the pupil will progress very rapidly, will be delighted with the work, and should be allowed to use as many specimens as time will permit.

§ 74, p. 98. This experiment is hardly practicable, but its description will serve to indicate to the pupil the *true* method of finding the centre of gravity of a mass.

§ 77, p. 104. The plank, Fig. 86, should have a shallow groove cut in it, to guide the ball. Teachers report very satisfactory results from this experiment.

§ 81, p. 108. "I require my pupils to draw the paths of projectiles at different angles, as indicated by the streams of water from the Eight-in-one apparatus with the tube elevated at different angles, and have obtained good results." — G. F. FORBES, Roxbury Latin School, Boston.

§ 81, p. 110. *Improved Apparatus for verifying the Second Law of Motion.* The rod *d*, Fig. 20, is drawn back toward the left, and the detent pin *c* is placed in one of the three slots. One of the brass balls is then placed on the projecting rod, and in contact with the end of the instrument as at *A*; the other ball is placed in the tube *B*. Release the detent, and the ball at *B*, struck by the rod *d*, is projected with a force (when the spring is under its greatest strain) of about 15 lbs. At the instant it escapes the end of tube *B*, and is free to fall, the rod leaves ball *A*, and the latter begins to fall. Both balls are pierced with holes, in order that the masses of both may be equal. It is believed that this apparatus is the only one of the kind which has given entire satisfaction.

Fig. 91, p. 111. For the pendulum *A* six iron balls are used, pierced by holes through their centers, through which a string is passed. The balls are kept in place by knots tied in the string.

The length of a pendulum, *e.g.*, *B*, is approximately the distance from the point of suspension to the center of the ball.

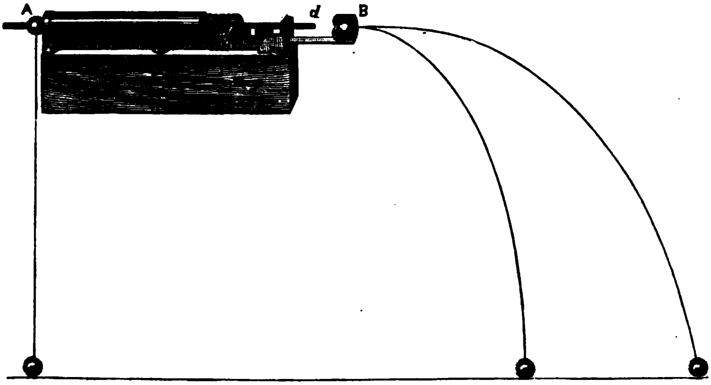


Fig. 20.

§ 82, p. 111. The center of oscillation is that point of a pendulum that vibrates in the same time, as if free from the influence of all other particles.

§ 88, p. 119. The usual mechanical definition of work is here given. A complete dynamical definition, of course, should be made to include negative as well as positive work, and may be stated as follows: When a force moves a body against resistance, or *alters the rate of motion of a body*, it is said to do work.

§ 92, p. 121. Potential energy — energy of position — has been called energy of stress, *i.e.*, energy due to stress. It is, really due to both position and stress. If we define stress provisionally as a pressure or a pull, then we shall find that pressure is transformed into the energy of motion *if the bodies pressed upon can move*, *i.e.*, are *in a position* which admits of motion.

§ 96, p. 126. The erg may also be defined as the work done in the latitude of the Northern States by raising $\frac{1}{980}$ of a gram-mass to the hight of 1^{cm}. The objection to this method of definition is that it is a variable measure. The same may be said of the foot-pound, which also evidently varies with locality, and must be reduced at each place to absolute units by the equation

$$\text{Work} = Fs = \text{weight} \times s = Mgs.$$

For example, in the Northern States the work done in raising a pound-mass through 1 foot is

$$Mgs = 1 \times 32.2 \times 1 = 32.2 \text{ foot-poundals.}$$

§ 101, p. 131. *Power.* The pupil should be informed that, in connection with machines, the term *power* has a technical signification which is quite distinct from its usual signification in dynamics. Here it is used in the sense of *force.*

§ 101, p. 132. *Law of Machines.* In a perfect machine (*i.e.*, one in which no internal work is done) the work done upon the machine ($= Fs$) is equal to the work done by the machine ($= F_1 s_1$); or, $Fs = F_1 s_1$; hence, $F : F_1 :: s : s_1$.

P. 135. *Levers.* If a teacher has a "plenty of time" (?) he may teach the popular but useless division of levers into three classes.

CHAPTER III.

HEAT.

§ 103, p. 139. When the water in this experiment nearly reaches the boiling-point, it will be forced out in a constant stream. Previous to that, it will only escape in drops.

§ 110, p. 142, Exp. 4. In the apparatus prepared especially for this experiment, several wires of different metals are fastened upon a board, and made to converge to a point where the flame is to be located. By running the fingers along the several wires toward the heated end, until they reach the point in each where the heat is unendurable, and noting the distance of these points respectively from the flame, the pupil is enabled to determine with a great degree of accuracy the relative conductivities of the several metals. He will notice that those metals which are the poorest conductors become incandescent first, and should be required to explain this phenomenon.

Exp. 5. The pupil should be directed carefully to avoid allowing the flame to touch the part of the tube not covered by the water.

§ 111, Exp. 1. The success of this experiment will depend largely upon the skill in manipulation, and had better be performed by the teacher only. It will be well to heat the water in the beaker as warm as can be borne by the hands before inserting the tube.

§ 112, p. 145. *Ventilation.* “The volume of air to be renewed in places requiring to be purified may be fixed as follows: —

	Per hour and per individual.
“ Hospitals:	
Ordinary cases	60 to 70^{cbm}
Wounded persons	100
At times of epidemics	150
Prisons	50
Workshops, ordinary	60
“ unhealthy	100
Theatres, music-halls, etc.	40
Long gatherings, meetings	60
Short gatherings, meetings	30
Infant schools	12 to 15
Adult schools	25 to 30
Stables, etc.	180 to 200

“These figures agree with those of English, American, and German hygienists.” — GENERAL MORIN, Director of the Conservatoire des Arts et Métiérs, at Paris.

§ 127, p. 158. "Let us suppose that the rarefaction is carried on so far that only one particle out of every original million is left in the space exhausted. The pressure is one-millionth of its original amount; but any molecule once in motion has one-millionth its former chance of encountering any other molecule, and, consequently, its average free-path is magnified a millionfold. The mean path would then be (Crookes) $\frac{1}{10000}^{\text{mm}} \times 1{,}000{,}000 = 100^{\text{mm}}$, or about 4 inches. By means of a good Sprengel pump, exhaustion to the hundred-millionth of an atmosphere can be attained, and the mean free-path of the gas so rarefied would be about 33 feet. In our atmosphere, at a hight of 210 miles, the single molecules are relatively so few (1000 to the ccm.) that each molecule might travel through a uniform atmosphere of that density for 60,000,000 miles without entering into collision. Beyond a hight of 300 miles, the atmosphere is so rare (less than one molecule per cubic foot) that the particles might freely travel through such an atmosphere from one fixed star to another." — DANIELL.

§ 116, p. 150. Other examples of abnormal expansion and contraction are Rose's fusible metal, iodide of silver, and India rubber. See "Elementary Treatise on Heat," by Balfour Stewart, 4th ed., p. 40.

P. 159, Exp. 3. Inasmuch as the water first receives the heat, and then communicates it to the ice, it is not possible to prevent the water, even though we constantly stir it, from becoming warmer than the ice. But the temperature of the ice will not rise above 0° C.

P. 161. *Boiling point.* "Dr. Carnelly finds that ice, if heated under an exceedingly small pressure, may be rendered very hot (180° C.), and will volatilize freely, yet without melting, unless the pressure be allowed to exceed a certain low maximum, which he calls the *critical pressure.*" — DANIELL.

§ 129, p. 162. The condenser furnished by the author consists of a vessel having a capacity of four to five liters, in which is coiled six feet of pure copper tube. The glass delivery tube *b*, Fig. 115, is connected with one end of this copper tube by a rubber connector. From the other end of the copper tube which pierces the vessel, near its bottom, escapes the distilled liquid. Cold water is siphoned into the condenser, as in the figure, and the heated water escapes near the top of the vessel through a delivery tube into a sink.

§ 130, p. 163. *Molecular Theory of Evaporation and Condensation.* "We have seen that in the case of a gas, some of the molecules have a much greater velocity than others, so that it is only to the average velocity of all the molecules that we can ascribe a definite value. It is probable that this is also true of the motions of the molecules of liquids, so that, though the average velocity may be much smaller than in the vapor of that liquid, some of the molecules in the liquid may have velocities equal to or greater than the average velocity in the vapor. If any of the molecules at the surface of the liquid have such velocities, and if they are moving *from* the liquid, they will escape from those forces which retain the other molecules as constituents of the liquid, and will fly about as vapor in the space outside the liquid. This is the *molecular theory of evaporation.* At the same time, a molecule of the vapor striking the liquid may become entangled among the molecules of the liquid, and may thus become part of the liquid. This is the molecular explanation of condensation. The number of molecules which pass from the liquid to the vapor depends on the temperature of the liquid. The number of molecules which pass from the vapor to the liquid depends upon the density of the vapor as well as its temperature. If the temperature of the vapor is the same as that of the liquid, evaporation will take place as long as more molecules are evaporated than condensed; but when the density of the vapor has increased to such a value that as many molecules are condensed as evaporated, then the vapor has attained its maximum density. It is then said to be saturated, and it is commonly supposed that evaporation ceases. According to the molecular theory, however, evaporation is still going on as fast as ever; only, condensation is also going on at an equal rate, since the proportions of liquid and of gas remain unchanged." — MAXWELL.

§ 132, p. 165, Exp. 1. For obvious reasons the results here stated are theoretical rather than practical, inasmuch as the water resulting from the melting ice cannot be kept at the same temperature as the ice.

More satisfactory results may be obtained by pouring 1^k of water at 80° C. upon 1^k of ice at 0° C., and noting the temperature of the liquid at the instant the ice becomes melted, and calculating from the data found the number of units of heat rendered latent.

§ 133, p. 167. *Latent heat.* "We now know that it is not heat of any kind; it is latent or potential energy. Work must be done upon ice in order to convert it into the more highly-stressed condition of water. Water differs from ice at the same temperature in possessing more potential energy." — DANIELL.

§ 135, p. 167. The reason for using two substances in this experiment rather than one is that a given quantity of water will dissolve more of both than of either alone; consequently, a greater amount of heat will be consumed.

§ 136, p. 167, Exp. 2. For the purpose of comparison, it would be well to take water at about 60° C., and fill the porous cup, and also a glass beaker of as nearly the same size and shape as practicable, and place a thermometer in each. In the course of five to ten minutes there will be quite a perceptible change in the temperature of the two bodies of liquid which had the same temperature at the beginning.

EXP. 3. The author finds that raising a window a little way, so as to get a good draft of air, answers much better than the use of the bellows. It may take at best from ten to fifteen minutes to freeze the water. Hence, it would be well to reduce the temperature of the water to a low point by means of a freezing mixture before introducing it into the tube.

§ 145, p. 174. The phrase "conservation of force" is sometimes used, but should be avoided, because it is entirely erroneous. A single illustration will make this apparent. Take a lever 12 ft. long, place the fulcrum 3 ft. from one end, and apply a force of 3 lbs. at the extremity of the long arm, and a force of 9 lbs. will be exerted at the other end of the lever. Here force is apparently created. If the force is applied at the extremity of the short arm, force apparently disappears. But though there is no conservation of force, there is a strict conservation of energy in this and in all other mechanical contrivances. On this principle is to be explained the paradox in the statement that a single-inch piston of the hydraulic press, pressed in with a force of 60 lbs., will commensurate a pressure of 60 lbs. to every square inch of a cylinder, however large.

You can store energy, but you cannot store force any more than you can store time. A stone resting on the ground presses the ground: force is all the time exerted, but the cleverest engineer could not drive a machine by using a weight resting on the ground.

§ 147, p. 175. *Joule's Equivalent.* According to Joule's revision of this physical constant, its value is, at sea-level at the latitude of Greenwich, 772.55 ft. lbs. In accordance with this value, the calorie = 423.985^{kgm} = 41,593,010,000 ergs.

If the numerical value is so chosen as to give the work corresponding to a unit of heat, it is called *Joule's Equivalent*, or the mechanical equivalent of heat; if, on the contrary, it gives the heat corresponding to a unit of work, it is called *the thermal equivalent of work.* If the former is denoted by J, the latter is $\frac{1}{J} = \frac{1}{423.985} = 0.00235$ calorie; *i.e.*, 1^{kgm} of work is equivalent to 0.00235 calorie of heat.

CHAPTER IV.

ELECTRICITY.

§ 151, p. 181. *Current.* Electricity, whatever it is, can pass from one body to another only by passing consecutively through every point of the path joining them. We may, therefore, with perfect propriety speak of a *current* of electricity.

§ 158, p. 184. "*How Electricity Originates.*" In the first edition of the Physics the foregoing expression, as well as the expression "generate electricity," were inadvertently used. These expressions, though often convenient, ought carefully to be avoided, as they convey erroneous ideas. Electricity is a *something* whose sum total in the universe seems to be constant, for we cannot alter the quantity contained in an isolated space by any method. We conclude that electricity is indestructible and uncreatable, by an exact parity of reasoning with that by which we are convinced that matter is indestructible and uncreatable.

When a body is electrified, another is always charged with an equal amount of the opposite kind of electricity, so that we may regard the process as, not the generation of anything, but a *separation.*

Exp. 4, p. 194. A suitable battery for this experiment consists of two Bunsen cells connected tandem. The electrolyte may be composed of sulphuric acid diluted with twenty times its volume of water.

§ 178, p. 203. "The resistance of all wires increases as the temperature rises, and the resistance of nearly all metals increases at the same rate, iron and thallium, according to Dr. Matthiesen, being the only exceptions. From the tables given by Latimer Clark we learn that the resistance of iron wire increases about thirty-five hundredths (0.35) per cent for each degree Fahrenheit, and that the resistance of copper increases, as the temperature rises, twenty-one hundredths (0.21) per cent for each degree.

"The rate of increase is not reckoned all through on the original resistance, but is computed in the same manner as compound interest on a sum of money. For example, if we have a wire which measures 100 ohms at 60° F., and the resistance be increased a certain amount by a rise of one degree in temperature, it will be increased by the next degree of rise at the same rate per cent, calculated on the original resistance, plus the amount increased by the first degree of rise." — LOCKWOOD.

Exp. 1, p. 215. As many as four Bunsen cells, connected abreast, should be used in this experiment, and the extremities of the wires should not dip more than 1^{mm} into the mercury. In using the apparatus illustrated in Fig. 152, a very strong current will be required.

Exp. 2, p. 216. In the apparatus furnished by the author for this experiment, zinc and carbon plates are used, and a solution of bichromate of potash, like that used in a Grenet cell, should be used in this floating battery. The battery, left to itself, will take up a position with its coil N and S.

§ 190, p. 218. Ampère's theory serves a very useful purpose in acquainting the pupil with very many phenomena of electricity and magnetism, and the laws governing them, very much as the fluid theory of electricity has, at least, furnished a very convenient language in which to express the various electrical phenomena. Yet, plausible as this theory seems in many of its aspects, it is open to many serious objections, of which we give only one. It would seem that, if this theory be true, force would be required to *demagnetize* instead of to magnetize matter; for, if the assumed molecular currents forming an inherent part of the constitution of matter really exist, they must, by the fundamental laws of electric currents, always arrange themselves in parallel order.

Exp. 3, p. 221. In performing this experiment, the glass plate should be thin, and should not touch the steel disk. It would be well to have a glass plate set in a wooden frame for this purpose.

§ 192, p. 222. *Magnetic Poles of the Earth, and Variation of the Needle.* "When the phenomena of terrestrial magnetism were first somewhat accurately observed, about 300 years ago, the needle pointed here in England a little to the east of north. A few years later it pointed due north; then, until about the year 1820, it went to the west of north, and now it is coming back towards the north. . . . Everything goes on as if the earth had a magnetic pole revolving at a distance of about twenty degrees round the true North Pole. . . . About 200 years from now we may expect the magnetic pole to be between England and the North Pole; and in England at that time the needle will point due north, and the dip will be greater than it has been for 1000 years, or will be again for another. That motion of the magnetic pole in a circle round the true North Pole has already, within the period during which accurate measurements have been made, extended to somewhat more than a quarter of the whole revolution." — SIR WILLIAM THOMSON.

§ 207, p. 237. The principal source of difference of potential is the *contact of dissimilar surfaces*, — that is, either of different substances, or of two pieces of the same substance whose surfaces are in different conditions. A piece of rosin and a piece of glass will, after contact, be more difficult to pull asunder than two pieces of rosin or two pieces of glass; and if they be rubbed together, so as to multiply the points of contact, the effect is multiplied. When pulled asunder, two such bodies are found to be charged equally and oppositely: across the surface of contact there has been a separation of positive from negative electricity. The development of electrical condition is thus necessarily a phenomenon of continual recurrence, and it greatly influences the adhesion of one body to another. In all probability, wherever there is friction, the energy ultimately converted into heat is, in the first place, converted into the energy of electrical separation.

"When two substances have different molecular velocities at their common surface of mutual contact, the molecules hamper one another, and energy is lost: this energy takes the form of the energy of electrical displacement." — DANIELL.

§ 233, p. 250. The quickest way to charge a battery of jars is to connect the inner coatings with one of the conductors of the electrical machine, and the outer coatings with the other conductor. Likewise, in using the Aurora tube, the top of the tube should be connected with one conductor and the bottom of the tube with the other. And the same is true of all other pieces of apparatus through which charges of electricity are to be sent.

Fig. 192, p. 254. A good substitute for the apparatus here described may be easily and cheaply prepared as follows: Apply a varnish, made by dissolving gum shellac in alcohol, to one side of a piece of window-glass about 6 inches long and 4 inches wide, and sift iron filings over the wet surface. As the alcohol evaporates, the gum will cause the filings to adhere firmly to the glass. The glass thus prepared may be used in the manner directed for the mica disk.

A piece of common mirror-glass also answers this purpose well.

§ 230, p. 256. Great E.M.F. is produced in every frictional machine, but it is an essential part of the contrivance that the rubber and the main conductor shall be separated by the insulator which is rubbed. We cannot, therefore, even if we connect the rubbers with the main conductor, complete a circuit, except through this insulator. Now this insulator has such an enormous resistance that, according to Ohm's Law, even the great E.M.F. produced by the machine can produce only a very feeble current.

§ 234, p. 259. *Voltaic Arc.* One may form a good idea of the size and shape of the arc by looking at it through a colored or smoked glass.

§ 245, p. 269. The following very clear and concise description of the operation of the telephone is taken, with slight modification, from Jenkins's "Manual of Electricity": —

"One instrument, which shall be called the receiver, is held to the ear. The person wishing to send a message speaks into the mouthpiece of the other instrument, which will be called the sender. The spoken words cause the air to vibrate in front of the sender, and the disk *E* of that instrument vibrates as the air does, alternately approaching and leaving the end of the magnet *M*. Each change in the position of the disk *E* causes a change in its magnetism, and in the magnetic field occupied by the coil *B*. Each change in the magnetic field causes an induced current in the circuit. This current is reversed at each change of direction in the motion of the disk, and, moreover, its magnitude is at each instant sensibly proportional to the rate at which the disk *E* is moving; for we know that the induced current is proportional to the rate of change in the field enclosed by the coil *B*, and we see that this rate of change will depend on the rate at which the disk *E* is moving. The induced currents acting on the receiving instrument will change the magnetism of the steel magnet *A* and the magnetic field in which the disk *E* of the receiver lies; each change will be accompanied by a change in the attraction of the iron disk to the magnet, and thus the disk *E* will be set in vibration. It will move to and fro as often as the direction of the current in the circuit is reversed; but, more than this, its rate of motion at each instant will be proportional to the rate of change in the magnetic field it occupies. Now, this rate of change is the same rate as that of the change in the current, which again is the same rate as that of the motion of the sending disk *E*. The motions of the sending and receiving disks will therefore be similar, though of unequal magnitude. The air, therefore, in front of them — which in one case moves the disk, and in the other is moved by it — will also vibrate in the same way; and, since the vibrations of the air at the sending end produced the impression of articulate words on the ear, so the vibrations of the air caused by the disk *E* at the receiving end will also produce the impression of the same articulate sounds. The chief difference between the two sounds is one of magnitude. The action of the two disks is similar to that in the toy telegraph, where two parchment disks are mechanically connected by a tight string. The electrical currents due to induction give those impulses in the one case which in the other are given mechanically by the string."

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CHAPTER V.

SOUND.

§ 267, p. 288. *Loudness of Sound.* "The sensible loudness of sounds does not coincide very closely with their physical intensity. This arises partly from modification in the form of the vibration induced by so complicated a transmission through the auditory apparatus, partly from causes purely physiological."— Daniell.

§ 274, p. 294. Very fair results may be obtained in these experiments with an ordinary tuning-fork. The forks mounted on resonance-boxes are considerably larger and more expensive than the ordinary tuning-fork, and are usually called *diapasons.* They should be set in vibration by bowing with a large bass bow, the bow having been previously rubbed over a piece of warm rosin. Avoid striking them upon hard substances, as permanent injury may be done them in this way. Another convenient way of setting them in vibration is by drawing quickly between the tines a rod of wood whose diameter is a little greater than the width of the space between the tines at their extremities. Diapasons should be carefully protected from rust, as this will alter their pitch. Diapasons like those in Fig. 214 require especial care, as a very little rust, or a very slight change in the elasticity of either one, may alter by a single vibration, or a part of a vibration, the vibration rate of one of them. In that case they must be tuned in unison by an experienced hand before they will answer again the purpose of showing sympathetic vibrations. To protect forks from rust, previous to laying away after use, they should be wiped with a woollen cloth slightly moistened with vaseline. Vaseline may be used to advantage to protect all pieces of apparatus made of iron or steel from rust.

§ 296, p. 321. The lowest sound is obtained by touching the center of one side and bowing the corner. The damping is best done by touching the plate with the extremity of the finger-nail. A node is always started from the point that is touched, while, of course, the point bowed is a ventral segment. The next note, a fifth above, is produced by damping the corner and bowing the center. By altering the position of the finger and bow, and sometimes using finger and thumb, a great variety of figures may be obtained, which may be further extended by changing the points of support.

If sand (fine writing sand is best) mixed with lycopodium powder is strewed upon a vibrating plate, the sand will collect on the nodal lines; but the lycopodium, by the agitation of the air, will be *blown* toward the center of each vibrating segment.

CHAPTER VI.

LIGHT.

§ 300, p. 325. *Kinds of Radiation.* "When a succession of waves impinges on a mass of ordinary matter, the effect varies according to the nature and the condition of the body which receives their shock; if it be an ordinary opaque mass, that mass may be warmed, wave-motion being transformed into heat, and the waves, which have impinged upon it, are *ex post facto* called a beam of radiant heat; if they fall upon the eye, they may produce a sensation of light, and the wave system is then called a beam of light; falling upon a sensitized photographic plate, or a living green leaf, it may operate chemical decomposition, and it is then called a beam of actinic rays. The word "rays" in the last phrase may be understood to mean, not imaginary lines at right angles to the wave-front, but kinds of radiation; and hence we speak of heat rays, of light rays, of chemical or actinic rays, these names being given to one and the same train of waves according to the effects which it is found competent to produce. But while ether-waves are in course of traversing the ether, there is neither heat, light, nor chemical decomposition; merely wave-motion and transference of energy by wave-motion. Hence, none of these names can in strictness be applied to a train of waves while these are actually travelling through the ether.

"According to Clerk Maxwell's view, the ether is a homogeneous body, a non-conductor of electricity. Periodic electric stresses applied to this produce waves which travel at the rate of about 300,000,000 meters per second. These waves are waves of transverse vibration, and there is no vibration longitudinal or normal to the wave-front."—DANIELL.

§ 311, p. 334. In a course of lectures given at the Lowell Institute in Boston, in 1882, Prof. S. P. Langley said that the light of the sun is two and a half times as brilliant as the same area of electric (arc) light; and that if a calcium light be held between the eye and the sun, the light would appear to be a black spot upon the sun. As a measure of comparison, in assisting the comprehension of the infinite quantity of light thrown off by the sun, he remarked that if there was an electric light of 2000 candle power on each square foot of the surface of the earth, then the whole light from the earth would be less than one-billionth that from the sun.

§ 301, p. 326. "We are led to infer, therefore, that there is such a medium, which we call the *luminiferous ether*, or simply the *ether;* that it can convey energy; that it can present it at any instant, partly in the form of kinetic, partly in that of potential energy; that it is, therefore, capable of displacement and of tension; and that it must have rigidity and elasticity. Calculation leads us to infer that its density is (Clerk Maxwell) $\frac{936}{1{,}000{,}000{,}000{,}000{,}000{,}000{,}000}$ that of water, or equal to that of our atmosphere at a hight of about 210 miles, a density vastly greater than that of the same atmosphere in the interstellar spaces; that its rigidity is about $\frac{1}{1{,}000{,}000{,}000}$ that of steel; hence, that it is easily displaceable by a moving mass; that it is not discontinuous or granular; and hence, that, as a whole, it may be compared to an impalpable and all-pervading jelly, through which *light* and *heat waves* are constantly throbbing, which is constantly being set in local strains and released from them, and being whirled in local vortices, thus producing the various phenomena of electricity and magnetism; and through which the particles of ordinary matter move freely, encountering but little retardation if any; for its elasticity, as it closes up behind each moving particle, is approximately perfect." — DANIELL.

"We are at liberty to deny the existence of all action at a distance, and attribute it to the intervening medium, which, to be logical, we must assume to be continuous and not molecular in constitution." — ROWLAND.

"It is a most wonderful fact that we have never been able to discover anything on the earth by which our motion through a medium can be directly proved. Carried, as we suppose, by the earth with immense velocity through the regions of space filled with ether, we have never yet been able to prove any direct influence from this ethereal wind." — ROWLAND.

§ 344, p. 373. "The bolometer, a curious instrument recently introduced by Prof. S. P. Langley for measuring minute quantities of radiant energy, promises important results in optical and astronomical investigations. It is based upon the fact that, when equal conductors of the electrical current are at the same temperature, their conductivities are equal, and the current of a battery can be equally divided between them; while, if unequally heated, their conductivities are unequal, and the difference in current can be detected with the galvanometer. By substituting thin sheets of metal for the wires ordinarily employed as conductors, so as to take up and part with its radiations with great rapidity, an instrument is produced capable of measuring such minute quantities of heat as 0.00001° C.; capable, also, of recording the infinitesimal heat radiations of the diffraction spectrum. The interesting statement is made in this connection, that the curves of light, heat, and actinism, instead of receding from each other, as commonly understood, are in reality coincident, that is, *the solar beam, instead of consisting of a pencil of rays bound into a luminous sheaf called light, is a homogeneous and simple energy, the names light, heat, and actinism being merely names for its different modes.*" — ELECTRICIAN.

§ 346, p. 375. *Effect of the Atmosphere on the Color of Sunlight.* "Sunlight is originally bright blue, and is extremely rich in the more refrangible rays, but filtration through two absorbent atmospheres — that of the sun and that of the earth — renders it a yellowish white." — LANGLEY.

§ 347, p. 378. It is now the received view that all color-perceptions, infinite as they may be in intensity and in hue, are due to the simultaneous excitation of three sets of nerve-ends by stimuli of relatively varying amount. These three physiologically-primary color sensations are (Young and Helmholtz) red, green, and violet. When orange light affects the eye, the nerve-ends sensitive to red are affected; those sensitive to green are affected, but less so, while those sensitive to violet are very feebly affected. When the red and green nerve-ends (as we may for convenience call them) are equally affected, the resultant impression is one of yellow; hence, a mixture of red *light* with green *light* produces a sensation of yellow. In like manner, the mixture of green and violet in varying proportions may produce all the color-sensations which the spectrum between the green and violet is capable of stimulating, as may be shown by the rotation of suitable color-disks.

§ 351, p. 379. *Interference.* "The twinkling of stars is another effect of interference: light coming to the eye from a star, so distant as to be practically a single luminous point, arrives in rays which have traversed slightly unequal distances in an irregularly refracting atmosphere, and thus enter the eye in unequal phases. Now one color is distinguished, now another; the eye perceives colored light complementary to that momentarily lost. No two persons can, as a rule, see any star twinkling in precisely the same manner. The planets twinkle only at their edges; their disks present many points or sources of light, whose scintillations, on the whole, mask one another." — DANIELL.

§ 353, p. 384. *Polarization.* "Ordinary light consists of vibrations taking place always in planes at right angles to the direction of the ray, but in all directions in those planes. That is, if the ray travels along the axle of a wheel, the vibrations composing it are all in the plane of the wheel, but are executed along any or all of the spokes.

"The effect of reflecting light at certain angles from certain substances, or of passing it through certain crystalline substances, is to cause all the vibrations to take place in the same direction, — that is, along one spoke of the wheel and the spoke opposite to it.

"The light is then said to be polarized. Now, if the wheel, without being rotated, be slid along the axle, the spoke along which the vibrations take place will trace out a plane.

"When no rotative force is applied to the polarized light, the vibrations all take place in this plane, and the light is said to be 'plane-polarized.'

"We cannot detect by the eye in what plane light is polarized, or, indeed, whether or not it is polarized at all. In order to do so, we have to take advantage of the following natural law: —

" Transparent bodies which have the power of polarizing light in any given plane are opaque to light already polarized in a plane at right angles to that plane ; and reflecting surfaces which have the power of polarizing light in a given plane will not reflect light which, when it falls on them, is already polarized in a plane at right angles to that plane.

" Thus, to determine in what plane light is polarized, we have only to take a crystal which has the power of polarizing light in a certain plane, fixed with regard to its axis, and to turn it round till the light is extinguished.

" We then know that the light is polarized in a plane at right angles to that plane in the crystal." — GORDON.

§ 356, p. 387. " Whatever light is, at each point of space there is something going on, whether displacement, or rotation, or something not yet imagined, but which is certainly of the nature of a directed quantity, the direction of which is normal to the direction of the ray. This is completely proved by the phenomena of interference." — MAXWELL.

PART IV.

TEST QUESTIONS.

1. Describe an experiment which you have performed at your home, and state the lesson derived from it.

2. Why, as you raise the vessel *B*, Fig. 22, Physics, higher and higher, is the rubber forced inward more and more?

3. Name some phenomena which are the result of the earth's attracting the moon and the moon's attracting the earth.—*Ans.* The former attraction mainly keeps the moon in her orbit, and the latter is one of the causes of tidal phenomena.

4. What is the distinction between *mass* and *weight?* Which better defines a body? Why?

5. If the earth were a homogeneous shell devoid of air, and a person were to jump from one side toward the center, where would he stop? Could he stop at the center? Would his path be straight or curved? Would his motion be accelerated, retarded, or uniform? What would be the effect produced upon the earth at the instant he jumps? If the earth and his body were perfectly elastic (*i.e.*, the coefficient of restitution = 1), how long would he continue to move? If in his journey through the hollow space he should let drop a ball, what would become of it?

6. If the earth were a homogeneous sphere, and a hole extended from surface to surface through the center, and the hole were a vacuum, and a ball should be dropped into it, where would it stop? Where would it have its maximum velocity? How long would it continue to move?

7. A coil of glass tubing, after being suspended for a year, became permanently stretched. What property does this phenomenon show that glass possesses?

8. One man holds one end of a rope in his hands, and another man pulls the other end of the rope with a force of 90 lbs. What force does the latter compel the former to exert in order to retain the rope in his hands? — *Ans.* 90 lbs.

9. Two men at opposite extremities of a rope pull each with a force of 100 lbs. What is the force exerted between them or the tension of the rope? — *Ans.* 100 lbs.

10. What force is necessary to separate a pair of Magdeburg hemispheres from which the air has been entirely exhausted, and whose diameter is five inches? — *Ans.* 294.5 lbs.

11. What force would be necessary to separate the above hemispheres at a place where the barometrical column is 20 inches? — *Ans.* 196.3 lbs.

12. What force would be necessary to separate the same hemispheres at sea-level if only one-fourth of the air has been removed from them? — *Ans.* 73.8 lbs.

13. A stone weighing a kilo rests upon a shelf, and another stone of the same weight is suspended by a string. What effect is produced by the force of gravity acting on each? — *Ans.* In the former case, pressure; in the latter, tension.

14. If the shelf is removed and the string is cut, what change in the effects of gravity will occur? — *Ans.* Pressure and tension will cease, and motion will be produced.

15. In the experiment with vessel *B*, Fig. 22, why is the rubber pressed in farther the higher the vessel is raised? Is it because the pressure of the air increases as the vessel is raised?

16. A cubical vessel, whose interior dimension is 6^{cm}, is filled with water and sits upon a table. What is the entire pressure exerted by the liquid tending to separate the sides of the containing vessel? — *Ans.* 216^{g}. The pressure of the liquid upon the bottom is 216^{g}. But this pressure does not tend to separate the bottom if there is no upward pressure against the top, the

weight of the liquid being supported by the table. The pressure against each of the four sides is 108^g, and the force tending to separate two opposite sides is 108^g; and the entire force tending to separate the two pairs of opposite sides is therefore 216^g.

17. A man jumps from an eminence. During his descent how does the pressure of his feet upon the soles of his shoes compare with his weight? Explain.

18. At what hight does a water barometer stand when the mercurial barometer stands at 30 inches? — *Ans.* 33¾ ft.

19. In an atmosphere where the pressure is two atmospheres, how long should a barometer tube be to measure the atmospheric pressure?

20. State Mariotte's Law, and how it may be verified.

21. In the Eight-in-one apparatus, why does not water flow from the orifices *b*, *c*, etc., when the plug *a* is out? — *Ans.* The descent of the water is unresisted; consequently, there is no downward pressure, and, for this reason, no lateral pressure.

22. If a man slides down a vertical rope, grasping it more or less firmly with a constant grip, how will the tension on the rope compare with his weight?

23. Why is there no lateral pressure in liquids falling freely? — *Ans.* There is no pressure in such a body of liquid in any direction, inasmuch as, according to the supposition, its motion, caused by the force of gravity, is unimpeded. See Physics, p. 44.

24. Place one body on another, and allow them to fall in a vacuum; would the former press upon the latter during the fall?

25. Show that a body having uniform motion must be in a state of equilibrium.

26. Why do fluids transmit pressure in every direction, while solids transmit it usually only in the direction in which the force acts?

27. Why does pressure in a body of liquid increase *as* its depth, while in a body of gas it increases *with* its depth?

28. Lay a piece of paper on the smooth surface of a board, and let both drop. They reach the ground together; but if separated and dropped simultaneously, the board reaches the ground first. Explain.

29. Raise the piston *t*, Fig. 43, p. 60, to the top of the cylinder *s*, and stop up the tube *u* at its opening into the cylinder. What force must be applied to the piston to pull it to the bottom of the cylinder, the area of the transverse section of the piston being 20^{qcm}? Suppose that the piston, at the beginning, is at the middle of the cylinder, will the force required to keep it in motion be constant? About how great will be the force when it reaches the bottom of the barrel? Suppose the force at that point is withdrawn, what will happen? Suppose the apparatus to be inverted, and a person were to blow with a force of 10^{g}, the area of the cross section of the bore of the tube being 1^{qcm}, what weight placed upon the piston might be sustained? If the free extremity of the tube is raised 2^{m} above the lower extremity of the piston, and water is poured into the tube until it is filled, what weight placed upon the piston will be sustained by the water? What name would the apparatus receive in the last case? Suppose that a plug, just fitting the interior of the tube, were forced into the tube pressing against the water, what would the apparatus become?

30. The diameter of the mouth of an air-pump receiver is 20^{cm}. Three-fourths of the air has been removed from the receiver. The receiver weighs 1.5^{k}. What force will be required to raise it from the pump-plate?

31. A person is on deck of a vessel which is moving due east at the rate of one mile an hour; at what rate must he walk due south-west in order that his resultant motion may be due south? What will be his southerly velocity? (Solve by constructing a diagram.)

32. A steamship is moving due north at the rate of 10 miles, the tide carries it due north-east at the rate of 2 miles an hour, while the wind carries it due north-west at the rate of 4 miles an hour; what is its actual course and velocity?

33. A ship is sailing due south-west at the rate of 8 miles an hour; what is its southerly velocity?

34. A boat is crossing a stream at the rate of 5 miles an hour. A person walks from the stern toward the prow at the rate of 3 miles an hour. Describe his several velocities, and state how great they are.

35. While sitting in your chair, what motions has the matter composing your body?

36. A door stands ajar; why is it not moved perceptibly on its hinges when a bullet is fired through it?

37. Draw an oblique line to represent the path of a boat crossing a river, and find the relative intensities of the current, and the force which propels the boat at right angles with the banks.

38. Represent by lines three forces acting at angles with one another on a body, and find their equilibrant.

39. In Fig. 75, p. 93, Physics, what is the relation of the force of gravity acting on the weight *w* to the forces represented by the lines *cA* and *cB*?

40. Locate a point *A* on your paper, and from it draw a horizontal line *AB* to the right to represent a force of 10 lbs., acting on a body at *A*. Draw from *A* another horizontal line *AC* to the left to represent another force of 10 lbs., acting on the same body at the same time. In what state will the body be as regards these two forces? What is the relation of each force to the other? — *Ans.* An equilibrant. Show that each force produces its own independent effect in accordance with the second law of motion. Resolve one of the forces into two components. Let the intensities of the two forces be as 8 : 10; represent their resultant, and answer the requirement.

41. Draw a vertical line *AB*. Let this represent the path in which a body at *A*, the lower extremity of the line, is to move. Draw from *A* a horizontal line *AC* to the right, to represent one force acting on the body. Construct a parallelogram, and find the direction and intensity of the other force.

Letter the line which represents it *AD*. What is the effect produced by the force represented by the line *AC*? Show that this force produces the same effect that it would produce if the force represented by *AD* were not acting on the body. In order to do this you must suppose the force acting in the line *AD* to be resolved into two components. What lines of your parallelogram represent them?

42. Represent by a parallelogram a case in which the intensity of the resultant is less than either of its two components. Explain why it is less.

43. (Fig. 75, Physics.) Draw on the blackboard line *CD* to represent the equilibrant of the force of gravity on *W*. Indicate the direction also of the strings *CA* and *CB*. Then, with *CD* as a diagonal, and with two of its sides lying in the direction *CA* and *CB*, construct a parallelogram; and, with the intensity of the force represented by *CD* known, ascertain, by comparing each of the sides lying in the line *CA* and *CB* with the line *CD*, the intensity of each of the component forces. Compare the results with the readings of the dynamometers *X* and *Y*.

The intensity of the force *CD* and one of its components *CA* being known, find the intensity of the other component. Draw the line *CD* of any desirable length. Draw a line in the direction *CA* as indicated by the string, making its length in comparison with *CD* proportional to the given forces. Complete the parallelogram with *CD* as a diagonal, and the line lying in the direction *CA* as one of its sides; and ascertain, by comparing the length of the line lying in the direction *CB* with the length of the line *CD*, the intensity of the other component. Verify the result by consulting the reading of the dynamometer *Y*.

44. Two forces of 20^k and 50^k act at an angle of 60°; find their equilibrant.

45. If two boats just alike are connected by a rope, and two men, one in each boat, pull on the rope, at what point between

them will they meet? At what point if only one man pulls? Why?

46. State three causes for the variation of gravity on the earth's surface.

47. Can you move without the aid of some other body?

48. Bodies at rest, with respect to the surface of the earth, are really in motion, and their motion is not constant nor in a straight line. Are the forces which act on them in equilibrium?

49. Upon which will the effect of a given force be greater, a body at rest or a body in motion?

50. Express the atmospheric pressure at sea-level in absolute units. — *Ans.* 1,012,634 dynes per square centimeter.

51. Why are "top-heavy" bodies unstable?

52. What mechanical advantage may be gained in a copying press in which the hands move through 1 inch, while the end of the screw descends $\frac{1}{142}$ inch? — *Ans.* $F = 142$.

53. What is the true way of measuring gravity or any other force? — *Ans.* By its effects in producing momentum.

54. How many cubic feet of water will a 10-horse-power engine raise in an hour from a mine 300 feet deep, a cubic ft. of water weighing $62\frac{1}{2}$ lbs.?

55. When a force acts on a body at right angles to the direction of its motion, so as to cause it to revolve in a circle, does it do work on the body? Why?

56. Does the sun do work on the planets, which revolve about it? Explain. — *Ans.* No; the force of its attraction merely alters the direction of their motion, but not their velocities, and, consequently, not their kinetic energy.

57. What is the weight of a body at any place? — *Ans.* It is its mass multiplied by the force of gravity at that place ($W = Mg$).

58. What force is required to lift one gram one centimeter? — *Ans.* 980 dynes in this latitude.

59. (*a*) A man whose weight is W stands on the platform of an elevator as it descends. If the platform descends with a

uniform acceleration of $\frac{1}{4}g$, what will be his pressure on the platform? (*b*) What will it be if the platform ascends with the same uniform acceleration?—*Ans.* (*a*) $\frac{3}{4}$ *W.* (*b*) $\frac{5}{4}$ *W.*

60. A stone weighing 15 lbs. lying upon the ground has a spring balance attached to it. A man raises the stone by pulling the spring balance. Will the force employed, as indicated by the spring balance, exceed 15 lbs., and why? If it exceeds, upon what will the excess depend?—*Ans.* It will exceed 15 lbs., the excess being employed in producing motion; and the magnitude of the excess will depend upon the rapidity with which it is moved.

61. A man carrying upon his shoulders a bag of sand weighing 100 lbs., jumps from an eminence. How great will be the pressure of the bag upon his shoulders during the descent, disregarding the resistance of the air?—*Ans.* There will be no pressure, since the man will offer *no resistance*, during the descent, to the action of gravity on the sand.

62. A hammer, whose weight is 1500 lbs., falls 10 ft. How far will it drive a pile into the earth against an average resistance of 10,000 lbs.?

63. What horse-power in a locomotive will be required to draw a train of cars at the rate of 10 miles an hour against a constant resistance of 50 tons?

64. Is friction force?—*Ans.* Yes; since, according to the definition of force, it tends to alter motion.

65. Is work force?—*Ans.* No; work is the product of force multiplied by the space through which it acts.

66. What is the product of force multiplied by the time during which it acts called?—*Ans.* Momentum.

67. When a force acts upon a body and causes it to move a given distance, in what language would you describe the effect of the force?—*Ans.* As work done on the body, or as energy communicated to the body.

68. How does energy differ from power?—*Ans.* The element of time has nothing to do with energy, while power means a capacity to do a given amount of work *in a given time.*

69. If an engine should raise 55 lbs. 10 ft. in a second, and at the end of a second its energy should be exhausted, could it properly be called a one-horse-power engine?—*Ans.* Yes; since while it did work, it performed at the rate of 33,000 ft. lbs. per minute, and this is just as truly a horse-power as it would be if the work were maintained for a thousand years.

70. A cannon ball is shot into empty space; how great a force will be required to deflect it from its path?—*Ans.* Since the body meets with no resistance, any force, however small, will suffice to deflect it from its path in accordance with the Second Law of Motion.

71. Can a child sitting on a sled start or stop the sled by pulling on a cord attached to the sled? Why?—*Ans.* No; since the sled will, in either case, receive both the action and reaction, which, being equal, would neutralize each other.

72. Why does not every body move when acted on by force?

73. Why does a body thrown horizontally into the air fall to the earth?

74. Is the expression "one horse-power per second" admissible, as, for instance, when we wish to convey the idea that a horse-power *lasts*, or is exerted *for* one second?—*Ans.* No; the expression would be equivalent to 33,000 ft. lbs. per second *per second.*

75. How many dynes of force are required to set a mass in motion?

76. How many dynes are required to make a gram-mass move with a velocity of 9.81^{m} per second, the force acting constantly for one second? What, if it act for two seconds?—*Ans.* 981 dynes; 490.5 dynes.

77. What is the force acting on a falling gram-mass in the Northern States?—*Ans.* 980 dynes.

78. What is the force acting on a falling pound-mass in the Northern States?—*Ans.* 32.191 poundals.

79. How many dynes are required to set a mass weighing 50^{k} in motion with a velocity of 12^{m} per second, the force acting for precisely one second?—*Ans.* 60,000,000.

80. What kind of energy is chemical energy? — *Ans.* Potential energy, inasmuch as it is due to forces tending to produce a rearrangement of molecules. It becomes kinetic when chemical action, *i.e.* rearrangement, takes place.

81. What kind of energy is the energy of compressed air? — *Ans.* Kinetic, since it is due to the motion of the air particles.

82. A body in space is entirely free to move (*i.e.*, free from the influence of all other bodies); how much force will be required to move it? — *Ans.* A body not constrained by other bodies (*i.e.*, perfectly free to move) is perfectly sensitive to the action of a force, so that the smallest force would move the largest mass.

83. Compare the velocities produced on masses of 1^k, 200^g, and 1^g of forces measuring 200,000, 40,000, and 200 dynes. — *Ans.* All equal if applied for the same length of time; 200^{cm} per second if the action endure one second.

84. Given a body in motion. At a given instant let it be left to itself and not acted on by any force. What will happen? (See Maxwell's "Matter and Motion," pp. 56, 57.)

85. (*a*) Which has the greater energy, a body moving at the rate of 20^m per second in a straight line, or one of the same mass moving with the same velocity in a circular path? (*b*) If the force which compels the latter to move in a circular path should cease to act, what would be its subsequent velocity? — *Ans.* (*a*) Their energies would be the same, for energy does not depend on direction or form of path, but on the velocity at each instant along the path. (*b*) The velocity would be 20^m per second.

86. Let two equal forces act for the same length of time, one on a body weighing 2^k, the other on a body weighing 6^k; how will the momenta produced compare?

87. Is a spring balance a force measurer or an energy measurer? Why will it not answer both purposes?

88. How can a power of 5 lbs. raise a ton 10 ft. with a perfect machine?

89. What power will raise 20 tons of coal 100 ft. in an hour?

90. How many times as much energy has a body moving 100 ft. per second than another body of the same weight moving 25 ft. per second? Compare their momenta.

91. How much faster will an iron ball weighing a pound fall than one weighing an ounce?

92. Imagine that a body having a mass of 40^g is at absolute rest in space, and is absolutely free from the action of all external forces. Now let a force of 20 dynes act upon it for five seconds in one direction. What will be the result? Is work done upon the body? (Inertia is not a resistance — is not a force.) When a body offers no resistance to the action of a force, what is the only effect produced by the force? What kind of motion is the result? What kind of energy will the body acquire, *i.e.*, kinetic or potential? What velocity will the body acquire? — *Ans.* $2\frac{1}{2}^{cm}$ per second. What amount of energy will be imparted to the body? — *Ans.* 50 ergs.

93. Is a pendulum which vibrates seconds at New York longer or shorter than one which vibrates seconds at the equator? Explain.

94. Which will tick oftener, a clock having an 8-inch pendulum or one having a 32-inch pendulum? How many times oftener?

95. From the laws of the pendulum derive a reason why a person with short legs naturally takes quicker steps than a person with longer legs.

96. Describe the transformations of energy that take place during a single swing of a pendulum.

97. Where will a given pendulum vibrate faster, at the top or at the foot of a mountain? Why?

98. Which will vibrate in a shorter time, a pendulum 10 inches long or one 15 inches long? How many times shorter?

99. Two clocks — one at the equator, the other at a pole — have pendulums of the same length. Which will gain on the other, and why?

100. It is sometimes necessary to use a pendulum less than a meter in length to beat seconds. How may this be accomplished? — *Ans.* By placing a bob on the pendulum rod above as well as below the center of motion. By moving this bob up and down the rod the pendulum may be made to move slow or fast as is desirable. The musician's *metronome* is an example.

101. A body starts from rest under the influence of a force which produces acceleration $a = 2$ feet; when will it have a velocity of 1000 ft. per second? — *Ans.* At the end of the 500th second.

102. A body travels at 12 ft. per second. In 10 seconds it is moving 7 ft. per seeond. What is the mean retardation? — *Ans.* $\frac{1}{2}$ foot per second.

103. Wherein is the absolute unit of force preferable to the gravitation unit of force? — *Ans.* The former is not affected by the variations in the force of gravity, and hence is everywhere the same, while the latter is subject to local variation.

104. The final velocity of a falling body weighing 5 lbs. on striking the ground is 100 ft. per second. "With what force will it strike the ground?" — *Ans.* The question as it stands is devoid of sense, for the time during which it acts (depending upon the rigidity of both the body and the earth) is not given. The question may be stated thus: What is the mean pressure between the body which has fallen and the earth on which it falls, if a velocity of 100 ft. per second is arrested in t units of time? Assume that t is $\frac{1}{2000}$ of a second. Since $v = at$; $v = 100$; $t = \frac{1}{2000}$; $a = 200{,}000$; and $F = ma = \frac{5}{32.2} \times 200{,}000 = 31{,}052.7 +$ lbs.

105. What is the velocity of a falling body at the end of the 5th second at a place where $g = 2^m$ per second? — *Ans.* 10^m per second.

106. A bullet is fired from a gun whose barrel is 30 inches long; describe its motion through the first 30 inches. — *Ans.* Its motion is accelerated, because it is acted upon by a continuous (not constant) force throughout this distance.

107. When a body is thrown horizontally into the air, why does it fall to the earth? What effect upon the rapidity and time of falling has its horizontal motion?

108. Suppose that a cubic centimeter of water at 4° C. to become frozen: (*a*) What will it weigh? (*b*) What will be its mass? Suppose it to be suspended by a thread: (*c*) What tension in the thread will it produce, measured by the gravitation system? (*d*) What, measured by the absolute system? — *Ans.* (*a*) Weighed by a balance-beam it will weigh one gram; weighed by a spring balance it will depend upon the locality; (*b*) its mass is one gram; (*c*) the same tension that would be produced under the same circumstances if a standard gram-mass (usually of platinum) were suspended, and both would depend upon the locality; (*d*) measured by the absolute system it would depend upon the locality: at sea level, in the latitude of Greenwich, it would be 981 dynes.

109. Suppose that you take a cubic centimeter of water at 4° C. and allow it to freeze: (*a*) How will its mass be affected? (*b*) What is its density before there is a change of temperature? (*c*) What, after it is frozen? (*d*) How is its volume affected by the change? — *Ans.* (*a*) Its mass will not be changed; (*b*) its density is 1; (*c*) its density will be less than 1; (*d*) its volume will be increased.

110. In the metric system what is the density of a body? — *Ans.* It is the number of grams in a cubic centimeter.

111. Given a solid, a vessel of water and a vessel of another liquid, and a pair of balances; state how you would find the specific gravity of the solid, the liquid, and the cubical contents of the solid.

112. State three methods of finding the specific gravity of a liquid.

113. Suggest an easy method of finding the cubical contents of a test-tube. — *Ans.* Ascertain the weight of the water it contains, and the weight in grams equals its contents in cubic centimeters.

114. A pebble-stone weighs in air 20^g; immersed in water it weighs 15^g; immersed in another liquid it weighs 17^g. What is the specific gravity of the latter liquid? What is the specific gravity of the stone? What is the cubical contents of the stone?

115. What is heat? Give some proof of your statement.

116. How will you explain the rush of air into the vacuum when an opening is made into an exhausted air-pump receiver?

117. What is the difference between a hot body and a cold body?

118. Why is the quantity of heat required to raise the temperature of a body of gas 1° very different when it is in an open vessel to what it is in a closed one? — *Ans.* When gases are heated in an open vessel, they expand very rapidly, and a considerable portion of the heat is expended in changing their bulk; in a closed vessel, the whole of the heat is spent in raising the temperature.

119. Name several processes by which the temperature of a body may be lowered without removing heat from it? — *Ans.* Expansion, evaporation, and liquefaction.

120. For what purpose is ice wrapped in flannels in the summer? — *Ans.* To exclude the heat.

121. Let a kilogram of mercury lose one calorie; how much will its temperature be lowered?

122. How high must a body be raised that on falling it will generate enough heat to raise its own weight of water 1° C.? — *Ans.* Suppose the body weighs one pound; then it must be raised $772 \times \frac{9}{5} =$ about 1390 ft. (See § 147, Physics.)

123. How many kilograms of ice at 0° C. can be melted by 1^k of steam at 100° C.? — *Ans.* $(537 + 100) \div 80 = 7.9^k+$.

124. How many kilograms of steam at 100° C. will melt 100^k of ice at 0° C.? — *Ans.* $(100 \times 80) \div (537 + 100) = 12.5^k+$.

125. What weight of steam at 100° C. would be required to raise 500^k of water from 0° C. to 10° C.?

Ans. $(500 \times 10) \div (537 + 90) = 7.9^k+$.

126. A current of 9 ampères worked on an electric arc-light, and, on measuring the difference of potential between the two carbons by an electrometer, it was found to be 140 volts. What was the amount of horse-power absorbed by this lamp?

Ans. $\frac{C \times V}{745} = \frac{9 \times 140}{745} = 1.66$ horse-powers. (See rule X., p. 69.)

127. How many incandescent lamps, requiring an E.M.F. of 60 volts and a current of 1.5 ampères each, can be supplied by an engine giving 15 useful horse-powers, the loss of energy in the dynamo being 20 per cent?—*Ans.* 80 per cent of 15 = 12, the horse-power of current available. From the tables, p. 76, 1 horse-power = (about) 746 volt-ampères, 1 lamp requires $1.5 \times 60 = 90$ volt-ampères; therefore, $\frac{12 \times 746}{90} = 100$ lamps, very nearly.

128. What amount of heat will be generated in each of the foregoing lamps per second?

Ans. $0.00024 \times (1.5 \times 60) = 0.00216$ calorie of heat.

129. An electric bell is in circuit with a voltaic cell which will furnish a current just sufficient to ring it. What will be necessary if ten such bells are introduced into the circuit? Why?—*Ans.* If a given current will ring one bell, it will ring any number of like bells. But as each bell introduced into the circuit increases the total resistance of the circuit, the E.M.F. must be correspondingly increased by the introduction of new cells in series, in order to maintain the same current.

130. Why does it require more voltaic cells to work a long telegraph line than a short one? How ought they to be connected? Why?

131. For each 50 ohms' resistance in a circuit, about 1 gravity-cell is required (Haskins). Suppose a line of wire 200 miles long (13 ohms' resistance to the mile), and 10 relays in the circuit: (*a*) What should be the theoretical resistance of each relay? (*b*) How many gravity-cells will be required to operate them?—*Ans.* (*a*) Disregarding the resistance of the battery (its resist-

ance in this case being relatively of no importance), the resistance of the circuit is $13 \times 200 = 2600$ ohms; hence, the resistance of the relays should be 2600 ohms, or 260 ohms in each relay. (*b*) The entire external resistance is $2600 + 2600 = 5200$ ohms; $5200 \div 50 = 104$, the number of cells required.

132. Ten Bunsen cells, whose E.M.F. $= 1.7$ and $r = 0.5$ ohm, are to be used in a circuit whose $R = 2$ ohms: (*a*) What will be the current if they are connected abreast? (*b*) What, if they are connected tandem? (*c*) What, if they are joined in pairs abreast, and the pairs are connected with one another tandem? (*d*) What, if they are divided into two groups of five each, the cells of each group connected abreast, and the two groups are connected tandem?

Ans. (*a*) $$C = \frac{E}{r + R} = \frac{1.7}{0.05 + 2} = 0.82 \text{ ampère.}$$

(*b*) $$\frac{17}{5 + 2} = 2.41+ \text{ ampères.}$$

(*c*) $$\frac{8.5}{0.25 \times 5 + 2} = 2.6+ \text{ ampères.}$$

(*d*) $$\frac{3.4}{0.1 \times 2 + 2} = 1.72+ \text{ ampères.}$$

133. The resistance of 5 inches of No. 32 platinum wire is about 0.05 ohm; how would you connect 4 Bunsen cells so as to develop in the wire the maximum quantity of heat?

Ans. $\sqrt{nr \div R} = \sqrt{4 \times 0.5 \div 0.05} = 6+$. The interpretation of this is, that all should be connected abreast.

134. What is the maximum amount of heat that can be developed in the wire per second with the four cells?

Ans. $$C = \frac{E}{r + R} = \frac{1.8}{0.125 + 0.05} = 10.2+ \text{ amperes.}$$

$$H = C^2 \times R \times t \times 0.00024 = 10.2^2 \times 0.05 \times 1 \times 0.00024$$
$$= 0.001248 \text{ calorie;}$$

or, sufficient heat can be developed to raise the temperature of 1.248^{cc} of water 1° C. per second.

135. What current will there be when 10 gravity-cells (E.M.F. = 1 volt each, and $r = 3$ ohms each) are connected in series through a wire whose resistance is 50 ohms?

$$\textit{Ans.}\quad C = \frac{E}{r + R} = \frac{10}{30 + 50} = 1.25 \text{ ampère.}$$

136. Show in the preceding question that, with an infinite number of cells in series, the current cannot possibly exceed 3⅓ ampères.

Ans. Since the external resistance in this case will become of comparatively no importance, it may be disregarded; then

$$C = \frac{E}{r} = \frac{1 \times \text{infinity}}{3 \times \text{infinity}} = 0.3\tfrac{1}{3} \text{ ampère.}$$

137. It is required to ring a bell over a No. 16 copper wire 300 ft. long, with three cells of Leclanché battery, the resistance of the wire being 0.0076 ohm per yard, and the resistance of a Leclanché cell being 1 ohm. What should be the resistance of the bell magnet to obtain the greatest magnetic power? —*Ans.* 0.76 ohm (the resistance of 300 ft. of wire) + 3 ohms (the resistance of three cells) = 3.76 ohms. The resistance of the circuit, not including the helix of the electro-magnet, is, therefore, 3.76 ohms; hence (Law 1 of electro-magnets), the resistance of the bell magnet should be 3.76 ohms.

138. What is the resistance of the carbon filament of an incandescent light in which there is a fall of potential of 60 volts, and the intensity of the current is 1.6 ampères?

$$\textit{Ans.}\quad R = \frac{E}{C} = \frac{60}{1.6} = 37\tfrac{1}{2} \text{ ohms.}$$

139. Explain the sparks seen at the circuit-breaker of an induction coil when in operation. —*Ans.* They are sparks produced by the extra currents at each "breaking" of the circuit.

140. A line 2 miles long, built of No. 8 iron wire whose resistance is 13 ohms per mile, has two bell magnets in circuit, and a battery of 10 Leclanché cells (r of each = 1 ohm). What should be the theoretical resistance of each bell magnet?

— *Ans.* Battery resistance 10 ohms + line resistance 26 ohms = 36 ohms. The sum of the resistances of the electro-magnets should then be 36 ohms, or 18 ohms each. But, as there would be likely to be some leakage, practically the resistance of each magnet should be some less than 18 ohms.

141. For which is the gravity battery better adapted, circuits of small or large resistance? Why? — *Ans.* For circuits of large resistance, since the large resistance of the battery then becomes of comparatively little importance.

142. You have 48 cells, each of 1.2 volt E.M.F., and each of 2 ohms' internal resistance. What is the best way of grouping them together when it is desired to send the strongest possible current through a circuit whose resistance is 12 ohms? — *Ans.* Group them three abreast. (See Law VIII., p. 69.)

143. Required the current in a circuit with 60 Grove cells, connected in series with 12 ohms' external resistance; $r = 0.6$ ohm, and $E = 1.8$ volts for each cell.

Ans. $C = \dfrac{108}{36 + 12} = 2.25$ ampères.

144. Required the current in the same circuit when the arrangement of the 60 cells is 30 series of 2 cells joined abreast.

Ans. $C = \dfrac{54}{9 + 12} = 2.56 +$ ampères.

145. Required the current in a circuit, with the same 60 cells connected in series, when $R = 2$ ohms.

Ans. $C = \dfrac{108}{36 + 2} = 2.85 +$ ampères.

146. Required the current in the last circuit with the arrangement of 12 cells in series, each consisting of 5 cells connected abreast.

Ans. $C = \dfrac{21.6}{1.44 + 2} = 6.27$ ampères.

147. How many Bunsen cells (E.M.F., 1.7 volts per cell) will be required to maintain an electric arc-light, whose resistance is 8 ohms, with a current of 9 ampères?

Ans. $C=\frac{E}{R}$; or, $E=CR=9\times 8=72$ volts; $72\div 1.7=42+$; hence, about 42 cells will be required.

148. What is the cause of a current of electricity?—*Ans.* A difference of potential at different points in the conductor through which it flows.

149. If two Bunsen cells are to be used in a circuit, with an external resistance of 2 ohms, should they be connected abreast or tandem? If two gravity cells should be used in the same circuit, by which method should they be connected?

150. What E.M.F. is required to maintain a current of 20 ampères in a circuit of 100 ohms' resistance?

Ans. $C=\frac{E}{R}$; whence $E=C\times R=20\times 100=2000$ volts.

151. What current will a battery having an E.M.F. of 4 volts furnish in a circuit whose total resistance is 10 ohms?

Ans. $C=\frac{E}{R}=\frac{4}{10}=0.4$ ampère.

152. What is the total resistance of a circuit in which a battery having an E.M.F. of 2 volts furnishes a current of 0.5 ampère? *Ans.* $C=\frac{E}{R}$; whence $R=\frac{E}{C}=\frac{2}{0.5}=4$ ohms.

153. What is the most convenient test of the E.M.F. of an electrical machine?—*Ans.* The length of the sparks which it will give.

154. If a sounding body moves, how will its motion affect the wave-length of the waves which it throws behind? How will it affect those thrown in front? How will the pitch of the sound compare as heard by a person in front and another behind?

155. When a voice an octave higher, such as that of a woman or boy, reproduces the same melody which has been sung by a man, we "hear again a part of what we have heard before." Explain.—*Ans.* A human voice conveys to the hearer not only the primes of the compound tones, but also their upper octaves,

and with less force the other upper overtones; hence a voice an octave higher would produce the upper octave previously given by the man, or a "part" of what was previously given.

156. What kind of vibration is that of a column of air in a pipe?—*Ans.* Longitudinal.

157. The picture on a stereopticon slide is two inches square. The slide is ten inches from the lens of a porte lumière. What will be the size of the image on the screen at a distance of 30 ft.?—*Ans.* $\frac{O}{I} = \frac{x}{2}$, or $\frac{360}{10} = \frac{x}{2}$; whence $x = 72$ in. $= 6$ ft., *i.e.*, the image is 6 ft. square.

158. What is the focal length of the lens used in the last question?

$$Ans.\ \frac{1}{o} + \frac{1}{i} = \frac{1}{f}, \text{ or } \frac{1}{360} + \frac{1}{10} = \frac{1}{f}; \text{ whence } f = 9.7 + \text{in.}$$

159. At what temperature does a body cease to radiate heat and light?—*Ans.* It ceases to radiate heat at the absolute zero; light at about 525° C.

160. What phenomenon shows that light does, in a small degree, pass around a corner?—*Ans.* Diffraction.

161. Why does a white body always appear of the same color as the light by which it is illuminated?

162. What proof can you give that the light of the electric spark does not proceed from an incandescent electric fluid (if there be such a substance) nor any etherial medium which is supposed to pervade all space?—*Ans.* Every line found in the spectrum of the light proceeding from the electric spark can be traced to some chemical substance existing either in the electrodes or in the space through which the electricity passes, and there are none that are common to all discharges, as would be the case if a common medium were rendered luminous.

163. A gas-burner must have what candle-power in order that it may illuminate a printed page as brightly at a distance of 5 ft. as a single candle at a distance of 1 ft.?—*Ans.* 25 candle-power.

164. How does one color differ from another color?

165. How do you explain the separation of colors when white light passes through an optical prism?

166. What is the general effect of a concave mirror on a beam of light? Name some other piece of optical apparatus that will produce the same effect.

167. Why is the image of a light as seen in water usually enormously elongated vertically?

168. Why is the same side of the moon always turned toward the earth? Does the moon rotate on its axis?

PART V.

SOLUTIONS TO PROBLEMS IN ELEMENTS OF PHYSICS.

CHAPTER II.

DYNAMICS.

PAGE 52. Q. 4. $76 : 49.2 :: 1033.3 : 668.92^{g} +$.

Q. 5. $76 : 98.2 :: 1033.3 : 1335.13^{g} +$.

PAGE 60. Q. 8. Any weight less than 10^{k} may be lifted.

PAGE 68. Q. 3. The pressure on the top is nothing; on the bottom it is $25 \times 20 \times 15^{g} = 7500^{g}$; on each of the sides it is $25 \times 15 \times 7.5^{g} = 2812.5^{g}$; and on the ends, $20 \times 15 \times 7.5^{g} = 2250^{g}$.

Q. 4. The additional pressure will be 100^{g} for every 4^{qcm} of area on the inner surface. The area of the bottom is 500^{qcm}; the additional pressure is, therefore,

$$\frac{500}{4} \times 100^{g} = 12{,}500^{g}.$$

This, also, is evidently the pressure on the top. The additional pressure on each of the sides is

$$\frac{375}{4} \times 100^{g} = 9375^{g};$$

and on each of the ends,

$$\frac{300}{4} \times 100^{g} = 7500^{g}.$$

PAGE 69. Q. 5. The total pressure on the bottom is $7500^{g} + 12{,}500^{g} = 20{,}000^{g}$; that on the top, $12{,}500^{g}$; on each side, $12{,}187.5^{g}$; on each end, 9.750^{g}.

Q. 6. The answers to Q. 3 would be 13.6 times greater: viz., $102{,}000^{g}$ on the bottom; $38{,}250^{g}$ on each side, and $30{,}600^{g}$ on each end.

In considering Q. 4, it makes no difference whether mercury or water is used. In the case of mercury, the total pressure on the bottom is evidently $102{,}000^{g} + 12{,}500^{g} = 114{,}500^{g}$; on the top, $12{,}500^{g}$; on each side, $38{,}250^{g} + 9375^{g} = 47{,}625^{g}$; and on each end, $30{,}600^{g} + 7500^{g} = 38{,}100^{g}$.

Q. 7. (*a*) The pressure on the bottom of the keg, when the tube is empty, is evidently 1200^{g}. (*b*) If the tube be filled, the column of water will be 1030^{cm} high, instead of 30^{cm}; therefore the pressure on the bottom is $40 \times 1030 = 41{,}200^{g}$. (*c*) The weight of the water in the tube is evidently 1000^{g}.

Q. 8. Assuming, for simplicity, that all parts of the box are at equal depths, the crushing force on each side would be equal to the weight of a column of water 1^{km} high, with a base of 1^{qm}; the volume of this is 1000^{cbm}, and its weight $1{,}000{,}000^{k}$.

Q. 9. Taking the atmospheric pressure at 1^{k} per square centimeter, the crushing force at the sea level, on each side, would be $10{,}000^{k}$.

Q. 10. Since the whole area of the top is 500^{qcm}, a pressure of 20^{g} on the plug would make a total pressure of

$$\frac{500}{4} \times 20^{g} = 2500^{g};$$

but, by the conditions of the problem, the top can sustain 50^{g} on each 10^{qcm}, or 2500^{g} total; therefore, it is clear that any pressure on the plug greater than 20^{g} would burst the vessel.

PAGE 84. Q. 1. $1033.3 \div 1.841 = 561.27^{cm} +$.

Q. 2. The 50^{g} of water when immersed in water is evidently buoyed up with a force of 50^{g}, and no weight is indicated.

Q. 3. The combined solids displace 102.88^{cc}. The sinker alone displaces 14^{cc}; $102.88^{cc} - 14^{cc} = 88.88^{cc}$; hence,

$$G = \frac{W}{W_1} = \frac{80}{88.88} = 0.9 + .$$

Q. 4. The weight of the water displaced, or the buoyant force when the oil is completely immersed, is greater than the weight of the oil; we have, then, two unequal forces in opposite directions, and the oil rises until the weight of the water displaced just equals the weight of the oil.

Q. 5. In the case of a floating tumbler, it will be noticed that by far the larger part of the water displaced is displaced not by the glass simply, but by the air in the bottom of the tumbler, and the *average density* of the combination of air and glass is less than the density of water, so the tumbler floats.

Q. 6. Iron vessels float for the same reason that the tumbler does.

Q. 7. From the table of specific gravities, we find that 1^{cc} of ice weighs 0.92^{g}, then 500^{cc} weigh 460^{g}; 460^{g} or 460^{cc} of water will be displaced, so that $500^{cc} - 460^{cc}$, or 40^{cc}, of ice will be above the surface.

Q. 8. Ice will sink in alcohol, since its specific gravity is greater than that of alcohol.

Q. 9. The weight of 500^{cc} of fresh water is 500^{g}, that of 500^{cc} of sea water is $500 \times 1.026^{g} = 513^{g}$, making 13^{g} more matter in the sea water than in the fresh water.

Q. 10. $\frac{50000}{19.36} = 2582.64^{cc} + .$

Q. 11. 19.36^{g} per cubic centimeter.

Q. 12. 0.24^{g} per cubic centimeter.

Q. 13. $\frac{1}{773}^{g}$ (0.0012932^{g}) per cubic centimeter.

Q. 14. The 53^{g} lost weight is the weight of an equal bulk of water, so the volume of the marble is 53^{cc}.

Q. 16. $\frac{1}{0.0012932} = 773.27^{cc}+.$

PAGE 85. Q. 17. $G = \frac{W}{W'}$, or $8.79 = \frac{1000}{W'}$; $\therefore W' = \frac{1000}{8.79} = 113.76^{g}$ = weight of an equal bulk of water. The piece of copper, therefore, weighs in water $1000^{g} - 113.76^{g} = 886.24^{g}$.

Q. 18. The cubical contents is $20 \times 10 \times 5^{cm} = 1000^{cc}$; therefore the weight is $1000 \times 11.35 = 11{,}350^{g}$.

Q. 19. It will lose the weight of an equal bulk of water, viz., 1000^{g}; thus weighing, when immersed, $10{,}350^{g}$.

Q. 20. Lead will float on the surface of mercury.

Q. 21. The weight that is lost is transferred to the liquid. (See Exp. 2, p. 76.)

Q. 22. $\frac{1015}{1000} = 1.015.$

Q. 23. $V = \frac{W}{D} = \frac{1000}{11.35} = 88.10^{cc}+$; the weight of an equal volume of air is $88.1 \times 0.0012932^{g} = 0.11393092^{g}+$ = the weight gained by weighing in a vacuum; therefore, the weight in a vacuum is $1000.11393092^{g}+$.

Q. 24. The specific gravity of the other liquid is

$$\frac{30-27}{30-26} = \frac{3}{4} = 0.75.$$

Q. 25. $G = \frac{W}{W'}$, or $W' = \frac{W}{G} = \frac{150}{10.47} = 14.32^{g}+$ = the weight supported by the water; $150^{g} - 14.32^{g} = 135.68^{g}+$, the weight supported by the string.

Q. 26. The weight of the boat is evidently the weight of 25^{cbm} of water, or $25{,}000^{k}$.

Q. 27. It would displace 50^{k} of water more, viz., $25{,}050^{k}$.

Q. 28. 100^{cbm} of water weighs $100{,}000^{k}$; the boat alone weighs $25{,}000^{k}$; therefore, it will take $75{,}000^{k}$ to sink the rail to the water-level.

Q. 29. $\dfrac{105.928-100}{102.4-100}=\dfrac{5.928}{2.4}=2.47.$

Q. 30. 1^{l} of water weighs 1000^{g}; the density of alcohol is 0.8; therefore, 1^{l} of alcohol weighs 800^{g}.

Q. 31. $V=\dfrac{W}{D}=\dfrac{50}{1.841}=27.15^{cc}+.$

Q. 32. $V=\dfrac{W}{D}=\dfrac{80}{1.42}=56.33^{cc}+.$

Q. 33. $W=V\times D=35\times 0.847=29.645^{g}.$

Q. 34. Each square centimeter must be able to sustain the weight of a column of water 2000^{cm} high, or $2000^{g}=2^{k}$ per square centimeter.

Q. 35. The bottom sustains $2500\times 50=125{,}000^{g}=125^{k}$; each side sustains one-half of this, viz., 62.5^{k}.

Q. 36. It will sink a little way, for the buoyant effect of the air on the part not immersed in the liquid will be removed.

PAGE 96. Q. 1. Let x represent the distance from the boy that the weight should be placed,

$$x:3-x::30:20;\ \text{whence, } x=1.8^{m}.$$

Q. 2. $40:260::50-x:x$; or, $x=43.33^{k}+=$ weight supported by the man; so the boy's load is $6.66^{k}+$.

Q. 3. Half a mile down the stream.

Q. 4. $\frac{1}{2}\sqrt{2}$ miles.

Q. 5. Half an hour.

Q. 6. $\frac{1}{2}\sqrt{2}\times 10=5\sqrt{2}$ miles per hour.

PAGE 107. Q. 1. $S=\frac{1}{2}gT^{2}=\frac{1}{2}\times 9.8^{m}\times 25=122.5^{m}$
$=\frac{1}{2}\times 32\frac{1}{6}\text{ ft.}\times 25=402.08+\text{ft.}$

Q. 2. $s=\frac{1}{2}g(2T-1)=\frac{1}{2}\times 9.8^{m}\times 9=44.1^{m}$
$=\frac{1}{2}\times 32\frac{1}{6}\text{ ft.}\times 9=144.74+\text{ft.}$

Q. 3. $V = gT = 9.8^{m} \times 5 = 49.0^{m} = 32\frac{1}{6}$ ft. $\times 5 = 160.83 +$ ft.

Q. 4. $S = \frac{1}{2}gT^{2} = \frac{1}{2} \times 9.8^{m} \times 49 = 240.1^{m} = \frac{1}{2} \times 32\frac{1}{6}$ ft. $\times 49$
$= 788.08 +$ ft.

Q. 5. $S = \frac{1}{2}kT^{2} = 500^{m} \times 3600 = 1{,}800{,}000^{m}$
$= 1640.42$ ft.[*] $\times 3600 = 5{,}905{,}512 +$ ft.

Q. 6. $V = \frac{1}{2}k \times 2T = 500^{m} \times 60 = 30{,}000^{m}$ per minute
$= 1640.42$ ft. $\times 60 = 98{,}425.2$ ft. per minute.

Q. 7. $s = \frac{1}{2}k(2T - 1) = 500^{m} \times 117 = 58{,}500^{m}$
$= 1640.42$ ft. $\times 117 = 191{,}929.14 +$ ft.

Q. 8. $S = \frac{1}{2}kT^{2} = 2^{m} \times 16 = 32^{m} = 6.56 +$ ft. $\times 16 = 104.96$ ft. from a point directly under that from which it started.

Q. 9. $V = \frac{1}{2}k \times 2T = 2^{m} \times 8 = 16^{m} = 6.56$ ft. $\times 8 = 52.48$ ft. per second.

Q. 10. $V = gT = 9.8^{m} \times 4 = 39.2^{m} = 32\frac{1}{6} \times 4 = 128.66 +$ ft. per second.

Q. 11. $V = gT = 9.8^{m} \times 3 = 29.4^{m} = 32\frac{1}{6} \times 3 = 96.5$ ft. per second.

Q. 12. It will rise in the first second as far as it would fall in the third.

$s = \frac{1}{2}g(2T - 1) = \frac{1}{2} \times 9.8^{m} \times 5 = 24.5^{m} = \frac{1}{2} \times 32\frac{1}{6}$ ft. $\times 5$
$= 80.41 +$ ft.

PAGE 111. Q. 1. They would vibrate in equal time, since the accelerative effect of gravity on all bodies is the same at the same place.

Q. 2. $1 : \frac{1}{2} :: \sqrt{0.993} : \sqrt{x}$, or $x = 0.248^{m}$
= the length of a pendulum beating half-seconds.

$1 : \frac{1}{4} :: \sqrt{0.993} : \sqrt{x}$, or $x = 0.062^{m}$
= length of one beating quarter-seconds.

$1 : 2 :: \sqrt{0.993} : \sqrt{x}$, or $x = 3.972^{m}$
= length of one beating once in two seconds.

[*] 1 foot $= 0.3048^{m}$.

$1 : 30 :: \sqrt{0.993} : \sqrt{x}$, or $x = 893.7^{m}$
= length of one beating once in thirty seconds or twice each minute.

Q. 3. $1 : \frac{60}{x} :: \sqrt{0.993} : \sqrt{0.4}$ where both lengths are expressed in meters, and x is the required number.

PAGE 116. Q. 1. Momentum = mass × velocity = $100,000 \times \frac{1}{6} = 16,666.66 +$ for the car, where the mass is expressed in pounds and the velocity in feet per second. The momentum of the ice = $500 \times 96.5 = 48,250$; so the momentum of the ice is nearly three times that of the car.

Q. 3. $25x = 80 \times 10 = 800$; therefore $x = 32^{km}$ per hour.

Q. 4. To double the momentum with a constant mass, the velocity must be doubled; to double the velocity the time must be doubled; but, by doubling the time a body is falling, the space is increased four-fold.

PAGE 130. Q. 5. The work $= 80 \times 4 \times 60 = 19,200^{kgm}$ per hour.

Q. 6. (*a*) Falling freely for 4 seconds, a body would fall through a space $S = \frac{1}{2}gT^2$, or $4.9 \times 16 = 78.4^{m}$; therefore, in order that a body weighing 50^{g} may rise 78.4^{m}, energy equal to 0.05×78.4, or 3.92^{kgm}, must be imparted to it.

(*b*) Here $S = 4.9 \times 25 = 122.5^{m}$, and the energy will be 0.05×122.5 or $6.125^{kgm} = \frac{25}{16}$ of 3.92^{kgm}; *i.e.*, the energy required to cause a body to rise 5 seconds is $\frac{25}{16}$ of that required to cause it to rise 4 seconds.

(*c*) The reason of this is that the initial velocity necessary to enable a body to rise 5 seconds is $\frac{5}{4}$ of that which would enable it to rise 4 seconds, and the energy increases as the square of the velocity.

Q. 7. Since the momentum of any moving body is proportional to the velocity; and since, in falling bodies, the velocity varies as the time, it follows that the momentum in the case (*b*) above is $\frac{5}{4}$ of that in (*a*).

Q. 8. Since the energy = weight into hight (Ws), the energy stored in 50^{k} 80^{m} high is $50 \times 80 = 4000^{kgm}$.

Q. 9. $\text{Energy} = \frac{WV^2}{2g} = \frac{50 \times 100^2}{2 \times 9.8} = 25{,}510.20^{kgm}+.$

Q. 10. $S = \frac{1}{2}gT^2 = 4.9 \times 16 = 78.4^{m}$;

$\text{energy} = WS = 50 \times 78.4 = 3920^{kgm}.$

Q. 11. If the 50^{k} should fall in air, a part of its energy would be transformed into heat.

Q. 12. $\text{Energy} = \frac{WV^2}{2g} = \frac{25 \times (29.4)^2}{2 \times 9.8} = 1102.5^{kgm}.$

Q. 13. During the ascent its energy is expended in doing work by lifting the 25^{k} to a hight against the force of gravity.

Q. 14. (*a*) Momentum $= MV = 50 \times 2 = 100$; again, for the 50^{g}, with a velocity of 100^{m} per second, we have : momentum $= MV = 0.05 \times 100 = 5$; therefore 50^{k} moving 2^{m} per second has 20 times the momentum of 50^{g} moving 100^{m} per second.

(*b*) $\text{Energy} = \frac{MV^2}{2g} = \frac{50 \times (2)^2}{2 \times 9.8} = 10.204^{kgm}$;

again, $\text{energy} = \frac{MV^2}{2g} = \frac{0.05 \times (100)^2}{2 \times 9.8} = 25.51^{kgm}$;

i.e., the energy in the second case is $\frac{5}{2}$ of that in the first.

Q. 15. Energy is the power of doing work; work is the overcoming of resistance through space; therefore it is its energy that enables one to determine the amount of resistance that a moving body can overcome.

Q. 16. A child can draw a carriage weighing 150^{k} because the energy required to overcome the resistance offered by the revolving wheels is much less than that required to raise 30^{k} against the force of gravity.

Q. 17. (*a*) The work of the horse is equivalent to that of raising 40^{k} 100^{m} per minute $= 4000^{kgm}$ per minute.

(*b*) Since 1 horse-power $= 4570^{kgm}$ per minute, 4000^{kgm} per minute $= \frac{4000}{4570}$ h.p. $= 0.87+$h.p.

Q. 18. 3^{km} per hour $= 50^{m}$ per minute; the power required to move 70^{k} 50^{m} per minute is 3500^{kgm} per minute $= \frac{3500}{4570}$ h.p. $= 0.76+$ h.p.

Q. 19. 5^{m} per hour $= \frac{1}{12}^{m}$ per minute; to raise $1{,}350{,}000^{k}$ $\frac{1}{12}^{m}$ will require $\frac{1}{12}$ of $1{,}350{,}000^{kgm}$ of work per minute $= 112{,}500^{kgm}$ $= \frac{112500}{4570}$ h.p. $= 24.61+$ h.p.

Q. 20. 10 tons = 20,000 lbs.; a 3 h.p. engine will raise 99,000 lbs. 1 ft. in 1 minute, or $\frac{1}{50}$ of $99{,}000 = 1980$ lbs. 50 ft. in 1 minute; therefore, to raise 20,000 lbs. 50 ft., it will take $\frac{20000}{1980} = 10.10+$ minutes.

Q. 21. A 2 h.p. engine will raise $2 \times 4570^{k} = 9140^{k}$ 1^{m} per minute; in 10 seconds the same engine will raise $\frac{1}{6} \times 9140^{k}$ $= 1523\frac{1}{3}^{k}$ 1^{m}; therefore, in the same time it will raise 1000^{k} $\frac{1523\frac{1}{3}^{m}}{1000} = 1.523^{m}+$.

Q. 22. A 5 h.p. engine can do 5×4570^{kgm} of work per minute, or $60 \times 5 \times 4570^{kgm} = 1{,}371{,}000^{kgm}$ per hour.

Q. 23. $\frac{1371000}{90000} = 15.23+$ days.

Q. 24. The energy increases as the square of the velocity; therefore, to increase the energy four-fold, the velocity must be doubled.

Page 135. Q. 1. (*a*) Since the power, multiplied by the distance through which it moves, must equal the weight multiplied by its distance, it is clear that the 10^{k} will be moved with a velocity of 2^{m} per second.

(*b*) $\frac{20}{50} = 0.4^{m}$ per second.

Q. 2. $Pp = Ww$; $\therefore$ $50 \times 100 = 2W$, or $W = 2500^{k}$. The advantage would be one of convenience, since a small power moving through a considerable distance can move a very great weight through a short distance. In common parlance we should say that "power" is gained.

Q. 6. $\frac{W}{P}=\frac{p}{w}$, or $\frac{4}{2}=\frac{p}{75-p}$; $\therefore p=50^{\text{cm}}$, *i.e.*, the prop must be 50^{cm} from the power end. The pressure on the prop will be, clearly, $2+4=6^{\text{k}}$ added to the weight of the lever.

Q. 9. Suppose the prop to be x^{cm} from the end from which 5^{k} are suspended, then $5x=20\,(70-x)$, or $x=56^{\text{cm}}$.

Q. 11. $3\,W=15\times 1$, or $W=5$ lbs.

PAGE 136. Q. 12. $6\times 3=1\times x$, or the number of spaces of P from the fulcrum is 18.

Q. 13. The power multiplied by its distance must equal the weight multiplied by its distance, *i.e.*, $240P=60\times 40$, or $P=10$.

Q. 14. $10^{\text{m}}=1000^{\text{cm}}$; since the circumference of the axle $=60^{\text{cm}}$, it will take $\frac{1000}{60}=16\frac{2}{3}$ turns to raise the bucket from the cavity. The power at each turn travels 240^{cm}; therefore, the whole distance that the power must travel is $16\frac{2}{3}\times 240^{\text{cm}}=4000^{\text{cm}}=40^{\text{m}}$.

Q. 15. (*a*) $\frac{W}{P}=\frac{p}{w}$, or $\frac{W}{1}=\frac{36}{4}$; $\therefore$ $W=9$ lbs.

(*b*) Again, $\frac{W'}{9}=\frac{30}{6}$; $\therefore$ $W'=45$ lbs.

(*c*) Again, $\frac{W''}{45}=\frac{40}{8}$; $\therefore W''=225$ lbs.

(*d*) $W''\times$ its velocity $=P\times$ its velocity; $\therefore$ P's velocity would be 225×5 ft. $=1125$ ft. per second.

Q. 16. The action of the wheel and axle is the same as that of a lever of which the fulcrum is at the centre of the axle;

$$\therefore \frac{P}{W}=\frac{\text{radius of axle}}{\text{radius of wheel}};$$

if the axle is a pinion, and the wheel has teeth by which it is turned by another wheel, then, since the circumferences are to each other as their radii, $\frac{P}{W}=\frac{N'}{N}$, where $N=$ the number of teeth on the wheel, and $N'=$ the number on the axle.

Q. 17. Applying the same principle that we have used so often, we have $\frac{W}{P}=\frac{p}{w}$, where p and w mean vertical distances. In the case of the inclined plane, $p=L$ and $w=H$; therefore, the general formula becomes $\frac{W}{P}=\frac{L}{H}$.

Q. 18. $\frac{W}{P}=\frac{L}{H}$; $\therefore \frac{200}{P}=\frac{12}{3}$, or $P=5$ lbs.

Q. 19. As in the case of all simple machines, so in the screw $Pp=Ww$, *i.e.*, $25\times 14\pi=\frac{1}{4}W$; whence, W, or the pressure beneath the screw, is 4398.24 lbs. We have supposed here that the parts move without friction.

Page 137. Q. 20. Here P moves through 10^{cm}, and W through $100-98=2^{cm}$; therefore, a force of 80^{g} applied in the direction *cd* will exert a lateral pressure of $\frac{10}{2}\times 80^{g}=400^{g}$.

CHAPTER III.

HEAT.

Page 148. Q. 4. The cubical contents of the room is $3\times 3\times 2.5^{m}=22.5^{cbm}=22{,}500^{cdm}$; since each person breathes 9^{cdm} of air per minute, two persons will be supplied $\frac{22500}{18}$ minutes $=1250$ minutes $=20\frac{5}{6}$ hours.

Q. 5. For 1000 persons 1000^{cbm} of *fresh* air is needed to keep the whole mass from becoming vitiated; the room contains $(35\times 18\times 7^{cbm})=4410^{cbm}$; therefore a complete change once in 4.41 minutes is necessary.

Page 153. Q. 1. Since 1° C. $=\frac{9}{5}$ of 1° F., 80° C. $=\frac{9}{5}$ of 80° F. $=$ 144° F.

Q. 2. Since 1° F. $=\frac{5}{9}$ of 1° C., 30° F. $=\frac{5}{9}$ of 30° C. $=16\frac{2}{3}$° C.

Q. 3. (*a*) The temperature of the room, after the fall, was clearly $68^\circ - 30^\circ = 38^\circ$ F.

(*b*) $\text{C.} = \frac{5}{9}(\text{F.} - 32) = \frac{5}{9}(68^\circ - 32^\circ) = 20^\circ$ C. before the fall; and $\frac{5}{9}(38^\circ - 32^\circ) = 3\frac{1}{3}^\circ$ C. after.

Page 154. Q. 4. $\frac{9}{5}\,\text{C.} + 32 = \text{F.}$;

$\therefore\ 100^\circ\ \text{C.} = 212^\circ\ \text{F.}$ $\qquad -20^\circ\ \text{C.} = -\ 4^\circ\ \text{F.}$
$40^\circ = 104^\circ$ $\qquad -40^\circ = -40^\circ$
$56^\circ = 132\frac{4}{5}^\circ$ $\qquad 80^\circ = 170^\circ$
$60^\circ = 140^\circ$ $\qquad 150^\circ = 302^\circ$
$0^\circ = 32^\circ$

Q. 5. $\frac{5}{9}(\text{F.} - 32) = \text{C.}$;

$\therefore\ 212^\circ\ \text{F.} = 100^\circ\ \text{C.}$ $\qquad -10^\circ\ \text{F.} = -23\frac{1}{3}^\circ\ \text{C.}$
$32^\circ = 0^\circ$ $\qquad -20^\circ = -28\frac{8}{9}^\circ$
$90^\circ = 32\frac{2}{9}^\circ$ $\qquad -40^\circ = -40^\circ$
$77^\circ = 25^\circ$ $\qquad 40^\circ = 4\frac{4}{9}^\circ$
$20^\circ = -\ 6\frac{2}{3}^\circ$ $\qquad 59^\circ = 15^\circ$
$10^\circ = -12\frac{2}{9}^\circ$ $\qquad 329^\circ = 165^\circ$

Page 156. Q. 1. Absolute temperature equals

$$\text{C.} + 273^\circ = \text{F.} + 460^\circ;$$

therefore, mercury boils at

$$(350^\circ + 273^\circ)\ \text{C.} = 623^\circ\ \text{C.},$$

or

$$(662^\circ + 460^\circ)\ \text{F.} = 1122^\circ\ \text{F.}$$

Mercury freezes at $(-38.8^\circ + 273^\circ)\ \text{C.} = 234.2^\circ$ C.,

or $(-37.8^\circ + 460^\circ)\ \text{F.} = 422.2^\circ\ \text{F.} =$ abs. temp.

Q. 2. (*a*) The increase in volume will be

$$\tfrac{75}{273}\ \text{of}\ 500 = 137.36^{cc}+;$$

therefore, the total volume at 75° C. $= 637.36^{cc}+$.

(*b*) In this case the decrease will be

$$\tfrac{20}{273}\ \text{of}\ 500^{cc} = 36.63^{cc}+,$$

so that the final volume will be

$$(500 - 36.63^{cc}+) = 463.37^{cc}+.$$

Page 157. Q. 4. 30° C. = 303° absolute temperature, and −15° C. = 258° absolute temperature; $1^l = 1000^{cc}$;

$$\therefore\ 303 : 258 :: 1000 : 851.48^{cc}+.$$

Q. 5. Calling the pressure of one atmosphere 1000^{g} per square centimeter, we have the proportion

$$900 : 1000 :: 1000 : 1111\tfrac{1}{9}^{cc}.$$

Q. 7. $1000 \times 1 : 1 \times 200 :: 273 : 54.6°$ absolute temperature, or − 218.4° C.

Q. 8.

Melting Points.		Boiling Points.	
Alcohol	Always liquid	Carbonic acid	195° C.
Mercury	234.2° C.	Ammonia	233°
Sulphuric acid	238.6°	Sulphurous acid	263°
Ice	273°	Ether	308°
Phosphorus	317°	Carbon bisulphide	321°
Sulphur	388°	Alcohol	351°
Tin	about 506°	Water	373°
Lead	607°	Mercury	623°
Zinc	698°		
Silver	1273°		
Gold	1473°		
Cast-iron	1323–1523°		
Wrought-iron	1773–1873°		
Iridium	2223°		

Q. 9. When the barometer is at 30 in., the pressure is 15 lbs. per square inch; and when it is at 29 in., the pressure is $\frac{29}{30}$ of 15 lbs. = 14.5 lbs. per square inch.

32° F. = 492° F. absolute temperature; 68° F. = 528° F. absolute temperature; hence, we may write the compound proportion

$$\left.\begin{array}{r} 528 : 492 \\ 15 : 14.5 \end{array}\right| :: \frac{1}{25} : \frac{1}{27.7}\text{ lbs.}$$

PAGE 173. Q. 1. To convert 1^{k} of ice at 0° C. into water at 0° C. requires 80 calories; to raise it to the boiling point requires 100 calories more, and to change this water into steam, 537 calories are necessary. The total heat that disappears in the change is, therefore, $80 + 100 + 537 = 717$ calories for each kilo, *i.e.*, 71,700 calories for 100^{k}.

Q. 2. (*a*) In condensing 1000^{k} of steam at 100° C. into liquid at 100° C., $1000 \times 537 = 537{,}000$ calories are liberated;

in falling from 100° C. to 80° C., the heat given off is evidently $1000 \times 20 = 20{,}000$ calories, making a total of 557,000 calories given out to the building.

(*b*) 1^k of water requires 100 calories to raise it from 0° C. to 100° C.; with 557,000 calories, then, we can raise 5570^k to the same temperature.

Q. 3. 50^k of water at 100° C. can impart 5000 calories to the ice; to melt 1^k of ice at 0° C. takes 80 calories; the amount of ice that may be melted is, then, $\frac{5000^k}{80} = 62.5^k = 137.73 +$ lbs.

Q. 4. $0.504 \times 10 + 80 + 10 = 95.04$ calories.

Q. 5. (*a*) When the water is at the boiling point, 100° C., 100 calories have been used for each kilo; the ice has been converted into water at 20° C., (*b*) each kilo having consumed 80 calories in melting.

Q. 7. If we call the resulting temperature $T°$, following the experiment with the sheet lead, we have the equation:—

$$\frac{T}{100 - T} = \text{specific heat of iron} = 0.1138;$$

or $$1.1138\,T = 11.38; \text{ whence } T = 10.21° + \text{ C.}$$

Q. 8. $\frac{5}{95} = \text{specific heat} = 0.0526 +$.

Q. 9. 50^k of water at 80° could transmit 4000 calories; but the specific heat of mercury is 0.0333; therefore 50^k of mercury at 80° can transmit only 0.0333 of $4000 = 133.2$ calories. Hence $133.2 \div 80 = 1.665^k$.

CHAPTER IV.

ELECTRICITY AND MAGNETISM.

PAGE 204. Q. 1. From the table (p. 203) we see that the ratio of the relative resistances of iron and copper is $\frac{6.46}{1.06} = 6.09 +$; ∴ $6.09 +$ miles of copper wire offers the same resistance as one mile of iron wire of the same size.

Q. 3. By referring again to the table, it is seen that by the addition of the acid the conductivity is made about 5000 times greater.

Q. 4. $\frac{2000000}{1.06}=1,886,792.45+$ times.

Q. 5. Employ plates of large surface, and place them near together.

Q. 6. $R=9.72\times\frac{500}{14^2}=24.7+$ ohms.

Q. 7. $1=9.72\times\frac{l}{6^2}$; $\therefore\ l=3.7+$ ft.

Q. 8. $R=127.3\times\frac{48}{14^2}=31.1+$ ohms.

Q. 9. $R=59.1\times\frac{5280}{175^2}=10.1+$ ohms.

PAGE 207.

Q. 1. $C=\frac{E}{R+r}=\frac{1}{10+2}=\frac{1}{12}$ ampère.

Q. 2. $C=\frac{E}{R+r}=\frac{1}{3+3}=\frac{1}{6}$ ampère.

Q. 3. $C=\frac{E}{R+r}=\frac{1.95}{3+3}=0.325$ ampère.

PAGE 209.

Q. 1. $C=\frac{E}{R+r}=\frac{10}{200+(0.5\times 10)}=0.048+$ ampère.

PAGE 210.

Q. 2. $C=\frac{E}{R+r}=\frac{40\times 1.95}{(1500+100)+(0.5\times 40)}$
$=0.048+$ ampère.

Q. 3. $R=k\frac{l}{d^2}=59.1\times\frac{5280}{165^2}=11.4+$ ohms:

$C=\frac{E}{R}$; or, $0.02=\frac{E}{0.5+11.4}$; whence

$E=0.238+$ volts;

therefore less than one cell would be sufficient.

Q. 4. Arranged in multiple arc,

$$C=\frac{1}{\frac{3}{210}+10}=\frac{210}{2103}=0.099+\text{ ampère};$$

arranged in series,

$$C=\frac{210}{(3\times 210)+10}=0.32+\text{ ampères},$$

showing that the latter arrangement is preferable.

Q. 5. In this case the current $C=\frac{10E}{10r+R}$; with one cell the current $C=\frac{E}{r+R}$. It is clear, then, that if R is very small, the current of one cell is about as strong as that of ten, and the consumption in the other nine is waste.

Q. 6. $$C=\frac{20}{\frac{20\times 3}{2}+120}=0.133+\text{ ampère}.$$

Q. 7. We may have any arrangement in which the number of series multiplied by the number of cells in each series equals 30; *e.g.*, 3 rows of 10 cells each; 5 of 6 each, etc. Suppose, first, that the whole 30 are connected in series; then,

(*a*) $$C=\frac{30}{(0.8\times 30)+10}=0.882+\text{ ampère};$$

if the cells are joined in 2 series of 15 cells each,

(*b*) $$C=\frac{15}{\frac{0.8\times 15}{2}+10}=0.937+\text{ ampère};$$

if in 3 series of 10 cells each,

(*c*) $$C=\frac{10}{\frac{0.8\times 10}{3}+10}=0.789+\text{ ampère}.$$

It is easily seen that with $R=10$ ohms, the arrangement (*b*) is best.

Let us take $R = 30$ ohms:

$$(a)\qquad C = \frac{30}{(0.8 \times 30) + 30} = 0.555 + \text{ ampère};$$

$$(b)\qquad C = \frac{15}{\frac{0.8 \times 15}{2} + 30} = 0.416 + \text{ ampère};$$

$$(c)\qquad C = \frac{10}{\frac{0.8 \times 10}{3} + 30} = 0.306 + \text{ ampère}.$$

In this case the arrangement (*a*) gives the largest value of C. In general, the best manner of grouping a given number of cells, in order to give the strongest possible current through a given external conductor, is that by which the internal and external resistances are as nearly equal as possible.

Applying this to the example above, we see that the internal resistances (r) in the three arrangements are 24 ohms, 6 ohms, and $2\frac{2}{3}$ ohms; and we found that $r = 6$ gave the best result when $R = 10$; and that $r = 24$ gives the best result when $R = 30$, both of which agree with the principle given above.

CHAPTER V.

SOUND.

PAGE 285. Q. 3. Since the velocity of sound in gases is inversely proportional to the square root of their densities, the densities will be inversely proportional to the squares of the velocities; *i.e.*,

$$\text{density of carbonic acid} : \text{density of air} : 331^2 :: 262^2;$$

or, the density of carbonic acid is 1.596+ times that of air.

PAGE 293. Q. 1. A fork vibrating 256 times per second produces wave-lengths twice as long as those produced by a fork vibrating 512 times per second.

Q. 2. Wave-length = 4 times the length of the resonance tube, or $4 \times 22.26^{\text{cm}} = 89.04^{\text{cm}} = 0.8904^{\text{m}}$. The velocity at 16° C. is 342^{m} per second; therefore $0.8904 = \frac{342}{\text{number of vibrations}}$, whence the required number is $\frac{342}{0.8904} = 384.09+$ vibrations.

Q. 3. Wave-length $= \frac{342}{384} = 0.89^{\text{m}}+ = 89^{\text{cm}}$.

PAGE 301. Q. 1. The vibration number of C'' is 528;

that of $D'' = \frac{9}{8}$ of $528 = 594$
" " $E'' = \frac{5}{4}$ " " $= 660$
" " $F'' = \frac{4}{3}$ " " $= 704$
" " $G'' = \frac{3}{2}$ " " $= 792$
" " $A'' = \frac{5}{3}$ " " $= 880$
" " $B'' = \frac{15}{8}$ " " $= 990$
" " $C''' = 2$ times $528 = 1056$

Q. 2. The vibration number of C_{-1} is $\frac{1}{2}$ that of $C = \frac{1}{2}$ of $132 = 66$.

Q. 3. Wave-length $= \frac{342}{\text{number of vibrations}}$;

∴ wave-length of $C' = \frac{342}{264} = 1.29^{\text{m}}+$
" " " $D' = \frac{342}{297} = 1.15^{\text{m}}+$
" " " $E' = \frac{342}{330} = 1.03^{\text{m}}+$
" " " $F' = \frac{342}{352} = 0.97^{\text{m}}+$
" " " $G' = \frac{342}{396} = 0.86^{\text{m}}+$
" " " $A' = \frac{342}{440} = 0.77^{\text{m}}+$
" " " $B' = \frac{342}{495} = 0.69^{\text{m}}+$
" " " $C'' = \frac{342}{528} = 0.64^{\text{m}}+$

Q. 4. The whole wave-length of C' we have found to be 129^{cm}; therefore, the length of the resonance tube is $\frac{1}{4}$ of $129^{\text{cm}} = 32.25^{\text{cm}}$.

Page 304. Q. 3. It is evident, from the table of Fig. 216, page 300, that the *F* string is $\frac{3}{4}$ as long as the *C* string.

Page 308. Q. 1. If *C* and *G* are sounded simultaneously, there will result for

$$\left.\begin{array}{llllllllll} C, & 1, & 2, & 3, & 4, & 5, & 6, & 7, & 8, & \text{etc.} \\ G, & & \frac{3}{2}, & 3, & & \frac{9}{2}, & 6, & & 9, & \text{etc.} \end{array}\right\} \text{times the number of vibra-}$$

tions made by the fundamental of *C*. From this arrangement, we see that the second overtone of *C* harmonizes with the first of *G*; the fifth of *C* with the third of *G*, etc.

Q. 2. The notes with their vibration ratios are as follows:—

C	*D*	*E*	*F*	*G*	*A*	*B*	*C′*
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

Coupling *C* with each of the following, the ratios of their respective vibration numbers are as follows:—

8 : 9, 4 : 5, 3 : 4, 2 : 3, 3 : 5, 8 : 15, 1 : 2;

arranging these on the required principle, we have first, *C* (1 : 1); then

C′ (1 : 2); *G* (2 : 3); *F* (3 : 4); *A* (3 : 5);
E (4 : 5); *D* (8 : 9); *B* (8 : 15).

* * *

CHAPTER VI.

LIGHT.

Page 335. Q. 1. A wall of each of the rooms would receive the same quantity of light; viz., $\frac{1}{6}$ of the total amount.

Q. 2. A wall of the first room contains 100 sq. ft., one of the third, 900 sq. ft.; since each wall receives the same total quantity of light, it is clear that the larger one receives only $\frac{1}{9}$ as much as the small one per square foot.

Q. 3. We may look upon the shadow as a pyramid of which the light is the apex and the boards right sections; now, the area of such a section varies as the square of its distance from the apex; the ratio of the distances is 1 : 3; the ratio of the areas is, therefore, 1 : 9.

If the board is withdrawn, the light, intercepted before, will illuminate 900^{qcm} of the screen.

Q. 4. The reason for the law of inverse squares is involved in the answer to the first part of Q. 3 above.

Q. 6. The ratio of the distances is 1 : 4; by the application of the laws of Inverse Squares, the ratio of the intensities at equal distances will be 1 : 16, *i.e.*, the gas flame may be said to have 16 candle-power.

PAGE 354. Q. 2. (*a*) The required relative index equals

$$\frac{\text{absolute index of diamond}}{\text{absolute index of water}} = \frac{2.5}{1.33} = 1.87+.$$

(*b*) The relative index equals $\frac{1.000294}{1.33} = 0.75+.$

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FEB 11 1916